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THE AGE OF THE AURIFEROUS GRAVELS OF THE SIERRA NEVADA.[1] WITH A REPORT ON THE FLORA OF INDEPENDENCE HILL.[2] [3]

IT is the purpose of this paper to attempt to fix more definitely than has hitherto been done the age of the auriferous, detrital rocks of the Sierra Nevada, resting uncomformably on the bed rock series, generally at considerable elevations above the present drainage and covered by volcanic flows. This series is commonly designated as the "Auriferous Gravels." It is also the purpose to indicate briefly the more salient features of the Cretaceous and Cenozoic history of the Sierra Nevada. The results are the outcome of a study of the range between the parallels of 38° 30′ and 39° 30′, extending over a number of years, and are to be set forth more fully in a bulletin now in preparation.

The auriferous gravels have been carefully studied by Professor Whitney, who determined them as fluviatile deposits and assigned to them a Pliocene Age, basing his conclusions chiefly on the palæobotanical studies of Professor Lesquereux. At the same time Professor Whitney states that very probably auriferous gravels may have accumulated during the whole of the Tertiary period. On the maps of the United States Geological

[1] By WALDEMAR LINDGREN.

[2] By F. H. KNOWLTON.

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Survey by Messrs. Turner and Diller and myself, the auriferous gravels have been indicated as "Neocene," including under this name the Miocene and the Pliocene. The same authors have correlated the lacustrine or brackish Ione formation along the western base of the Sierra with the fluviatile auriferous gravels on the flank of the range, and the two former authors have considered the age of both as probably Miocene,[1] basing their conclusions upon the more recent palæobotanical determinations of Professors Leo Lesquereux, Lester F. Ward, and F. H. Knowlton. Recently Professor Lawson[2] accepts Professor Whitney's determination of the auriferous gravels as Pliocene and thinks that the determination of the eroded surface on which rest the Ione formation and the auriferous gravels, as Miocene, may be in need of revision.

STRATIGRAPHIC RELATIONS OF THE AURIFEROUS GRAVELS.

The investigations of the United States Geological Survey have fully confirmed the earlier results as to the fluviatile character of the auriferous gravels over the whole flank of the Sierra Nevada above an elevation of a few hundred feet above the present sea level. Along the western base and at the northern end the auriferous gravels merge into brackish and lacustrine deposits. Along the western base the latter have been but little disturbed, while, according to Mr. Diller, they have experienced a considerable elevation at the northern end of the range. In a former publication[3] I have indicated the direction and the grade of the channels over a part of the western slope and investigated the character of the surface on which the gravels rest. The surface is that of a gently sloping, greatly eroded mountain range, but by no means reduced to a base level and not even to be considered as a peneplain. Only on the

[1] 8th Ann. Report U. S. Geol. Survey, p. 420.
14th " " " " " p. 466.
14th " " " " " p. 423.
American Geologist, Vol. XV, June 1895, p. 375.
[2] Bull. Dep. Geol., Univ. Calif., Vol. I, No. 4, p. 157.
[3] Bull. Geol. Sci. Am., Vol IV, p. 270.

middle and lower slopes of this range did the gravels accumulate.

In the principal broad Neocene river valleys one may generally distinguish the following formations:

A. The Ante-Volcanic Deposits.

1. *The deep gravels.*—These, usually hard and compact, coarse gravels fill the deepest trough-shaped depressions to a maximum depth of about 200 feet, usually 100 to 150 feet.

2. *The bench gravels.*—Covering the deep gravels and attaining a maximum depth of 300 feet, the bench gravels are spread out often to a width of one or two miles on the sloping shelves on both sides of the deepest trough. They are frequently very quartzose and more admixed with finer sediments than the deep gravels.

B. The Volcanic and Inter-Volcanic Deposits.

3. *The rhyolitic tuffs.*—Sweeping down the main river channels from the vents in the high Sierra, the flows of white rhyolite, accompanied by large masses of rhyolitic tuff, of clayey and sandy character, covered the bench gravels. These rhyolitic flows attain on the middle slopes a maximum depth of about 200 feet, while higher up they are much heavier. Much of this tuff is in the mining region designated as pipe-clay or chalk.

4. *The gravels of the rhyolitic period.*—The effects of the rhyolitic flows were to dam many lateral streams, thus causing immediate accumulations of gravels, clay, and sands. During the intervals between the rhyolitic eruptions the streams cut down new channels in the soft material and accumulated masses of gravel in their new beds. All these detrital masses of gravel, sand, and clay, generally of a finer character than the bench gravels, and usually containing rhyolitic pebbles, are designated as the "*gravels of the rhyolitic period.*" In many places, such as Nevada City, Nevada county, and the Long Canyon divide, Placer County, the rhyolitic gravels attain a thickness of several hundred feet.

5. *The gravels of the inter-volcanic erosion period.*—The interval separating the rhyolitic from the andesitic outbursts apparently differed in length at various points in the Sierra Nevada. While in some places, such as along the lower courses of the Middle and South Yuba, the andesitic tuffs lie almost conformably over the rhyolitic tuff, there are at other points, such as on the Forest Hill divide, near Placerville, and along the Mokelumne, indications of a relatively short period of a very active erosion, beginning immediately after the rhyolitic flows, or in some places shortly after the first flows of andesitic tuffs. This erosion was of a remarkably intense character, cutting sharp V-shaped canyons in new channels through the older beds, and in some places even down into the solid bed rock to a depth of about 100 feet. This action is so very different from that of the ante-rhyolitic and rhyolitic streams that the inference is justified that just after the rhyolitic flows the tilting of the slope took place, or at least began. In the bottom of these sharply cut channels a few feet of gravel accumulated along stretches with less grade, while, where the gorges were narrow and the grade steep no detritus is found. These are the gravels of the inter-volcanic erosion period.

6. *The andesitic tuffs and tuffaceous breccias.*—The andesitic tuffs poured down the river valleys in the form of successive mud flows of enormous volume, at first as sandy and clayey masses, but later mixed with a great quantity of larger angular or subangular fragments of hornblende and pyroxene-andesite, at last covering a large part of the slope and forcing the rivers to seek entirely new channels.

Along the valley border the Ione formation corresponds to the ante-volcanic bench gravels along the old rivers in the Sierra. The oldest or deep gravels of the river courses correspond to the fluviatile deposits in depressions in the surface on which rests the Ione formation; in other words, before the Ione transgression the rivers extended westward, probably to the center of the valley. The volcanic period is, along the valley border, represented by a series of gravels, sands, and tuffs spread over the Ione formation.

THE PALÆOBOTANICAL EVIDENCE OF AGE.

Almost the only means of determining the age of the auriferous gravels is afforded by the numerous plant remains which they sometimes contain. Remains of vertebrate animals have been found, but as Mr. H. W. Turner has pointed out, there is much doubt as to whether certain of the occurrences described by Whitney really belong to the auriferous gravels, so that this line of evidence does not at present lead to any satisfactory conclusions.

The age of the deep gravels.—No fossils of any kind have, as far as I am aware, been found in these beds. The coarse character of the gravels is largely responsible for this. As the bench gravels will be shown in the following pages to be of Miocene Age, the deep gravels are manifestly older, and some of them may be Eocene, but hardly older.

The age of the bench gravels.—The best and most extensive collections come from the upper part of the bench gravels, or from the very lowest part of the rhyolitic tuffs.

The Chalk Bluffs locality.—The largest collection examined by Professor Lesquereux was gathered by Mr. C. D. Voy, at Chalk Bluffs, near You Bet, Nevada county, and it therefore becomes desirable to indicate its exact horizon. You Bet is situated on the main channel of the Neocene South Fork of the Yuba, and the leaves occur at an elevation of about 3000 feet. The stratigraphic relations are extremely similar to those of Iowa Hill (Fig. 1) a little further south on the drainage of the old American River. There are the same deep gravels and heavy spreading bench gravels, capped by rhyolitic tuffs and andesitic tuffaceous breccia.

A bluff of the volcanic beds has been exposed by the hydraulic mining operations, and owes its name to the brilliant white color of the rhyolite. The exact locality from which the leaves came is a matter of some doubt, and is now covered by sliding débris. I was told by residents that they occurred at a place near the top of the bench gravels just below the rhyolitic

beds; on the other hand Professor Whitney states in his volume on the auriferous gravels that the matrix in which the fossils occurred was rhyolitic tuff. Professor Andrew Lawson kindly sent me some fragments of the matrix from the collection now preserved in the University of California. They are soft grayish to brownish compact clays which did not, under the microscope, give any evidence of volcanic origin; the extremely fine grain, may, however, have masked their original character. This much is certain that the fossils came from the uppermost bench gravels, or the lowest rhyolitic tuffs and about 500 feet above the bottom of the channel.

The Independence Hill locality.—In 1891 Dr. Cooper Curtice, on the request of Dr. G. F. Becker, visited many places in the gold belt to collect fossils. Among these were the Washington

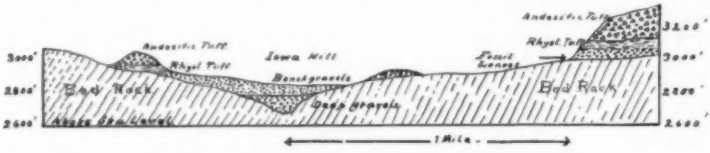

FIG. 1. General cross-section at Iowa Hill.

gravel mine at Independence Hill, near Iowa Hill, Placer county. Mr. J. B. Hobson, the owner of the mine, first directed our attention to the occurrence. A very fine and extensive collection of fossil leaves was obtained. The leaves occur in a whitish or bluish consolidated clay or shale which at first is soft, but on exposure becomes moderately hard and brittle. This shale was interbedded with gravels near the base of the 200 feet high bluff produced by the hydraulic work. A glance at the section (Fig. 1) shows that the lower part of the bluff forms a part of the bench gravels (2) which again are overlain by rhyolite tuff (3) and gravels of the rhyolitic period (4). The fossils consequently come from the uppermost gravels of the ante-volcanic period. Professor Knowlton after making a careful study of this collection, remarks on it as follows: "Dr. Curtice's is the first large collection of plants that has been obtained from the aurif-

erous gravels since the material was collected which furnished the basis of Professor Lesquereux's investigations of this interesting flora. A number of smaller collections made from time to time by various members of the survey have also been studied by Professor Lesquereaux, but they were from isolated and separated localities and furnish comparatively little additional information as to the age of these deposits. The present excellent collection is therefore of special interest. The vegetable remains represented are in general very finely preserved and admit of careful and satisfactory study. Most of the species are represented by ample material and some of them, by a large series thus making possible a much more thorough biological study than could heretofore be made. Almost all of this material has been determined, the only portion remaining unidentified being a number of fragments and a few either with obscure impressions or with doubtful affinities.

The collection as outlined above, embraces fifty-six species of which number ten appear to be new to science. The new species belong to the following genera: *Arisæmites*, *Ficus*, *Ulmus*, *Rhus*, *Zisyphus*, *Æsculus*, *Castanea*, and *Viburnum*.

These forms considered merely in the light of new species of course have little value in determining the age, but a more extended research through the literature on the subject than it has been possible to give at this time would undoubtedly bring out points of relationship or possibly of identity and they would then have a value as bearing upon the question of age. Until this can be done they must all be left out of consideration. As was to have been expected, a large number of the species were identified with those described by Professor Lesquereux in his paper on the flora of the auriferous gravels. Of the fifty-six species twenty have never been found in other deposits. Many of them were compared by Professor Lesquereux to living species and undoubtedly influenced him in deciding that the formation was of comparatively recent age. I have not had an opportunity of comparing these species myself, and until this can be thoroughly done they cannot be taken account of in the present connection.

Twenty species have also been identified in other formations, the six remaining forms making up the fifty-six species being of doubtful affinities. The following hastily prepared table shows the distribution of those forms.

TABLE SHOWING IDENTIFICATIONS OF FOSSIL PLANTS FROM INDEPENDENCE HILL, CALIFORNIA.

Species	Laramie	Laramie of California	Fort Union	Green River	Oligocene	Miocene	Pliocene	Remarks
Salvinia Alleni Lx.	..	..	..	×	..	..	..	Green River only.
Ficus tiliæfolia Lx.	×	..	×	×	×	×	×	
Ficus cf. *F. populina* Heer.	..	..	..	×	..	×	..	
Ficus cf. *F. planicostata* Heer.	×	..	..	..	..	..	..	Laramie only.
Ulmus Californica Lx.	..	..	..	..	..	×	..	
Populus Zaddachi Heer.	..	..	..	×	..	×	×	¾ Miocene.
Castanea Ungeri Heer.	×?	..	..	..	..	×	×	½ Miocene.
Juglans cf. *J. picroides* Heer.	..	..	..	..	..	×	..	Miocene only.
Acer aequidentatum Lx.	..	..	..	×	..	..	×	
Viburnum tilioides Ward.	..	..	×	..	..	..	..	Fort Union only.
Viburnum elongatum Ward.	..	..	×	..	..	..	..	
Viburnum Whymperi Heer.	×?	..	×	..	..	×	..	Miocene sp.
Cornus hyperborea Heer.	..	×	..	..	..	×	..	¾ Miocene.
Aralia Whitneyi Lx.	..	..	..	..	..	×	×	
Persea pseudo Carolinensis Lx.	..	..	..	..	..	×	×	
Laurus Californica Lx.	..	..	..	..	..	×	×	California only.
Magnolia Californica Lx.	..	..	..	..	..	×	×	
Magnolia lanceolata Lx.	×?	..	..	..	..	×	×	

A study of this table shows that twelve species have been found in the Miocene in various parts of the world. Of this number five are almost exclusively confined to this horizon, and may be regarded as typical Miocene forms.

Only nine of the nineteen forms are found in the Pliocene, and two of these are from the so-called Pliocene of California and therefore have little weight. None of these nine species is confined to this horizon. It will be observed that five species are accredited to the Laramie; of this number two are from Cherry Creek, Oregon, the age of which is only provisionally regarded as Laramie, the probability being that it is younger. Another species, *Viburnum Whymperi*, is doubtfully identified in the Laramie, being a characteristic Miocene species. A single

fragmentary leaf has been compared to *Ficus planicostata* Lx., a typical Laramie species, but the material is insufficient for a satisfactory determination. *Ficus tiliæfolia* Lx. has also been found in the Laramie at Golden, Colorado, but its principal range is in the Miocene and Pliocene.

Cornus hyperborea was found by Lesquereux in California in strata said to be Laramie, but the evidence seems insufficient and the horizon is much more likely to be later.

The Fort Union group is presented by no less than four species, three of them belonging to the genus *Viburnum*, and one to *Ficus*, while five species are found in the Green River group (Eocene) with one species (*Salvinia Alleni*) heretofore entirely confined to it. Two species have also been found in the Oligocene. From this tentative review it is seen that all of the species having a distribution outside of the auriferous gravels belong to formations of Pliocene or older age; none of them are more recent or living. The number wholly or mainly Miocene considerably exceeds the number found in any other ho.izon, and none of the species are apparently confined to the Pliocene. While the evidence is not yet sufficiently worked out to permit a positive statement, it seems to point very clearly to the Miocene Age of this deposit.

The following is a list of fossil plants found at Independence Hill. Quite a number are without doubt new to science, but as they have never been published I have simply given the generic name.

Salvinia Alleni Lx.
Arisæmites n. sp.
Ficus sordida Lx.
Ficus asiminæfolia Lx.
Ficus tiliæfolia Al. Br.
Ficus sp.
Ficus sp.
Artocarpus Californica Kn.
Ulmus Californica Lx.
Ulmus officinis Lx.
Ulmus pseudo-fulva Lx.
Ulmus n. sp.?
Ulmus fruit of.
Platanus appendiculata Lx.
Juglans egregia Lx.
Juglans sp.?
Hicoria ? fruit.
Salix Californica Lx.
Populus Zaddachi Heer.
Betula æqualis Lx.
Betula or *Alnus*, fruit.
Quercus convexa Lx.

Quercus distincta Lx.
Quercus elænoides Lx.
Quercus castanopsis ? Lx.
Quercus Boweniana Lx.
Castanea Ungeri. Heer.
Castanea n. sp.?
Castanopsis chrysophylloides Lx.
Corylus sp.
Magnolia lanceolata Lx.
Magnolia Californica Lx.
Liquidambar, fruit.
Acer æquidentatum Lx.
Acer fruit.
Rhus myricæfolia Lx.
Rhus dispersa Lx.
Rhus Boweniana Lx.
Rhus n. sp.
Æsculus n. sp.
Æsculus fruit.
Aralia Whitneyi Lx.
Aralia angustiloba Lx.
Laurus Californica Lx.
Persea pseudo-Carolinensis Lx.
Zizyphus piperoidas Lx.
Zizyphus n. sp.
Viburnum tilioides Ward.
Viburnum Whymperi Ward.
Viburnum elongatum ? Ward
Viburnum n. sp.
Viburnum fruit.
Cornus ovalis Lx.
Cornus hyperborea Heer.
Cornus n. sp.
Cercocarpus antiquus Lx.

This list, it should be remembered, is tentative and is likely to be modified by further collections or possibly to some extent by additional study.

The age of the Ione formation.—The flora found in the Ione formation is rather meager. North of 39° 30′ Messrs. Diller and Turner[1] have at several places found a scant flora considered by Professors Lesquereux, Ward and Knowlton to be of Miocene age and contemporaneous with the auriferous gravels. At Volcano hill, Placer county, H. W. Turner found fragments of leaves partly identical with those from Chalk Bluffs and Professor Knowlton considers them as probably Miocene.

In the Marysville Buttes, in the center of the Sacramento Valley I found a series of beds resting on the Tejon which I correlated with the Ione formation. In these a number of shells were found which Messrs. Stearns and Dall regarded as Miocene. The following forms were identified:

Crassatella Collina Conr.
Venericardia borealis Conr.
Verticardia ? sp.
Acila castrensis Hinds.
Macoma sp.
Tapes (Cuneus) sp.
Saxidomus sp.
Cardium modestum.

[1] J. S. DILLER, Lassen Peak District, 8th Ann. Rep., U. S. G. S., p. 419. H. W. TURNER, Rocks of the Sierra Nevada, 14th Ann. Rep., U. S. G. S., p. 462.

Liocardium apicinum Cpr. *Galerus* sp.
Fusus (Exilia) sp.

Independently, however, of this flora and fauna the stratigraphic evidence connecting the Ione formation with the antevolcanic bench gravels is positively and unmistakably indicated, and the two can at numerous points be shown to run over one into another; thus south and north of Rocklin, Placer county, and at the mouth of the Yuba as well as north and south of the area here specially treated. As the bench gravels, the Ione formation is overlain by rhyolitic and andesitic tuffaceous beds.

Age of the rhyolitic tuffs and associated gravels.—These are but slightly younger than the bench gravels, but no flora has been studied from them unless that of the Chalk Bluffs be partly from that horizon.

Age of the gravels of the intervolcanic erosion period.—Leaves have been collected by Diller from Monte Cristo gravel mine, Spanish Peak, Plumas county, which are from a bed overlain by andesite and, according to Turner, pretty certainly later in age than the white quartz gravels, although not positively representing the period of the andesitic flows.[1] In Mohawk Valley Turner has collected leaves from the Neocene lake beds containing rhyolitic fragments and covered by andesitic tuffs. According to Professor Knowlton[2] these are closely related to the flora of the auriferous gravels. The leaves from Tuolumne Table Mountain are also, according to Turner, later than the auriferous gravels proper.

Among the localities described by Professor Whitney is Bowen's tunnel, Placer county, two miles north of Michigan Bluffs. Regarding this place, Professor Whitney writes, using the notes of Goodyear (Auriferous Gravels, p. 93). "The gravel averages a foot or two in the middle of the channel. Over the gravel is first a mass of 'chocolate'" (a brown consolidated clay, probably a volcanic mud) "from one to four feet in thickness; above this is the gray cement" (andesitic tuff)

[1] Am. Jour. Sci., June 1895.

[2] Fourteenth Ann. Rep., U. S. G. S., p. 466.

"similar to that of the Reed mine near Deadwood. This 'chocolate' contains leaves of deciduous and coniferous trees in tolerably good preservation." Now, Bowen's channel, correctly described above, is a typical example of the narrow valleys eroded shortly before the main andesitic outflows, and its flora is distinctly later than that of the Chalk Bluffs and Independence Hill and just antedates the main andesitic tuffaceous breccia flows. Lesquereux[1] describes the following species from this locality:

Quercus Boweniana Lx. Resembles certain living Mexican forms.
Rhus Boweniana Lx.
Zanthoxylon diversifolium Lx. Closely related to *Z. integrifolium* Heer (Swiss Miocene).
Acer vitifolium Al. Br. (Swiss Miocene).

The conifer leaves, mentioned by Whitney, do not appear to have been determined. Though meager, this flora is evidently closely connected, if not identical with that from the bench gravels and is probably Miocene. Still another locality mentioned by Professor Whitney is that of North Fork tunnel near Forest City, Sierra county. From the description of Professor Pettee (Auriferous Gravels, p. 437) it appears that the leaves found occurred in a sandy clay resting on a gravelly "cement" and directly covered by andesitic tuff. It is not quite clear whether by this "cement" is understood a volcanic tuff, but in any case it seems plain that the leaves could have antedated the andesitic tuff but a short time. This occurrence, which is considerably above the deepest gravels of the vicinity and not now accessible should probably also be connected with the inter-volcanic period of erosion. The elevation of this locality is nearly 5000 feet. The leaves are species of *Quercus* and *Acer* and Lesquereux remarks that it is Miocene by one species of Quercus and one of Acer, while it also has of each of these one species identical or closely resembling certain living Mexican forms.

While the flora of the gravels of the inter-volcanic erosion

[1] Report on the Fossil Plants: Appendix to WHITNEY'S Auriferous Gravels.

period is scant and no positive conclusions as to age can be drawn from it, it must be conceded that it is very closely allied to that of the bench gravels. While more extensive collections might show it to be of Pliocene age, yet the characteristic forms contained in it prove that up to the beginning of the rapidly succeeding andesitic flows there was no great change of climate.

Age of the andesitic flows.—Mr. Turner has at various points found fossil wood in the andesitic tuffs (Alpine county, elevation 7000 feet) which Professor Knowlton has identified as coniferous and designated as *Cupressinoxylon* and *Pityoxylon*.[1] No trees referable to the former genus occur at this elevation at the present time, from which it may be inferred that the climate during the andesitic period was milder than now.

To recapitulate, the deep gravels are probably of Eocene or Lower Miocene Age, the bench gravels and the rhyolitic tuffs are with considerable certainty of Miocene, probably Upper Miocene Age. The age of the gravels of the inter-volcanic erosion period and of the andesitic tuff is not established beyond doubt, but probably belongs to the lower Pliocene or Upper Miocene. The eroded surface upon which the auriferous gravels were deposited was consequently produced either during the earliest Miocene or during the Eocene.

It is of interest to note that Professor Knowlton in his extended studies of the floras of the Yellowstone National Park,[2] has found a flora which he calls the Lamar flora and refers to the Upper Miocene; this flora he states bears a very close resemblance to that of the auriferous gravels.

REVIEW OF THE POST-JURASSIC HISTORY OF THE SIERRA NEVADA.[3]

In the following lines a short summary is given of the different phases of the history of the Sierra Nevada between the

[1] Am. Geologist, Vol. XV, June 1895, p. 375.

[2] ARNOLD HAGUE, The Age of the Igneous Rocks of the Yellowstone National Park, Am. Jour. Sci., June 1896, p. 452.

[3] Unless otherwise stated, the results in this paper have only reference to the belt here studied. Many of them will be applicable to the whole range, but this needs confirmatory study.

parallels of 38° 30′ and 39° 30′. Space forbids in this place anything but a mention of the results attained.

The early Cretaceous.—The grand features of the initiation of the Cretaceous were the plication and welding of the Mariposa beds with the older sediments, active eruptions continued from the Jurassic period of the lofty volcanoes along the foothills, then the seashore, and the intrusion, in the foundations of the range, of enormous masses—batholites—of dioritic and granitic magma. Of the mountain range occupying the site of the Sierra Nevada at this time we know but little. The Sierra Nevada and the Great Basin were evidently not differentiated. A very active erosion planed down this range to a peneplain or at least to a comparatively gentle topography. At this time, probably shortly before the deposition of the Chico Cretaceous, the first break took place, separating the Sierra Nevada from the interior basin.

The orogenic disturbance was probably of a twofold character. It included the lifting up of the whole region between the Wasatch and the Pacific in arching form, and a simultaneous breaking in and settling down of the higher portions of the arch. Thus the Sierra Nevada crust fragment was formed, the larger part of which has ever since remained a comparatively rigid block. Along the eastern margin the system of fractures was outlined (see Fig. 2) which towards the close of the Tertiary was to be still further emphasized. The faults along these fractures were largely of normal character. The movement did not take place evenly along all of these faults, hardly any occurring in some places, while along other parts of the system the whole of the fault was confined to this time.

The main break occurred along a line extending from near Markleeville by Genoa up towards Reno, and the displacement reached a maximum of 3000 feet. The fault along the western side of Antelope Valley, which probably will prove to be continuous with the Mono Lake fault, also appears to have been broken at this time. But the large crust block west of this first mentioned line proved too great to sustain itself, and a large part

of it, bordered by parallel fault lines, sank down. This sunken area is now indicated by Lake Tahoe and by its continuation northward, the Sierra Valley, only separated from each other by masses of Tertiary lavas. The Tahoe-Sierra Valley "Graben"

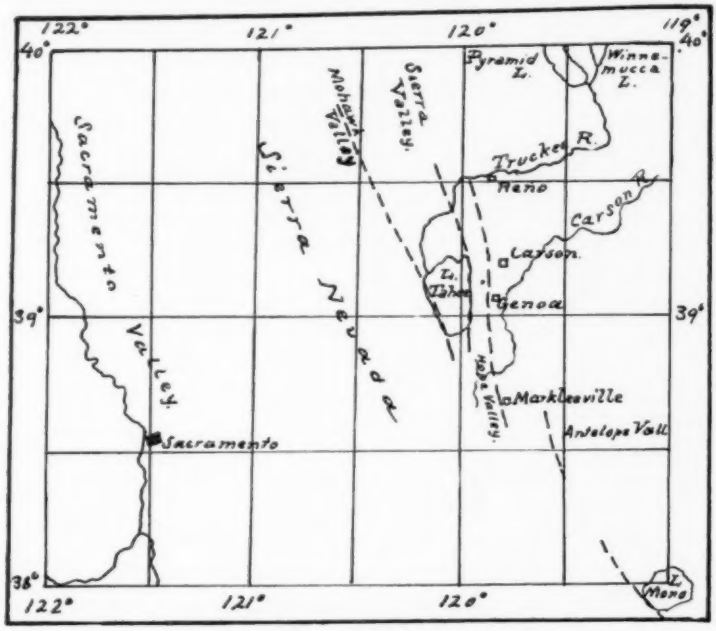

FIG. 2. Fault lines of the Sierra Nevada.

or "Moat" (the later word hesitatingly proposed as an English equivalent), is bordered on the west by the fault line beginning at Mt. Tallac, and extending by Donner, Independence and Weber lakes up towards Sierra Valley and Mohawk Valley. At this latter place the investigations of Mr. Turner indicate that the displacement may to a great extent at least be of Miocene Age. On the east it is bordered by the very distinct fault-line extending along the east side of Lake Tahoe up east of Boca and towards the east side of Sierra Valley. The long ridge between

the latter fault and the main break facing the Great Basin has very pronouncedly the character of a "Horst" or "Buttress" (the latter expression has been suggested by Mr. S. F. Emmons) — a block standing between two sunken areas.

This view then implies a gradual arching of the whole western part of the continent and a simultaneous sinking of parts of this uplifted crustal fragment, by reason of gravity, along longitudinal fractures. It is in close conformity with the previously announced views of King and Le Conte.

The newly formed block of the Sierra Nevada was at once attacked by the erosion; at first probably narrow canyons were cut in it, similar to those of today, though not so deep.

Chico period; close of the Cretaceous.— At this time the shore line along the western base advanced eastward and reached at least an elevation of 300 feet above the present sea level, possibly considerably higher. The Chico sandstones were laid down on an uneven surface, the foothills showing a relief at least as prominent as those of today. This important event is referred to as the Chico transgression.

The Téjon period (Eocene).— During the Chico and the Téjon the erosion was steadily at work on the flank of the Sierra Nevada, the first deep canyons were widened to broad valleys in the lower and middle parts of the range, while still preserving their character nearer the crest. There is no evidence of any Eocene deposits along the valley border in this latitude, though marine Eocene occurs in the Marysville Buttes in the center of the Great Valley and also further south on the east side of the San Joaquin Valley. Sediments of this age may have been deposited between 29° 30′ and 38° 30′, but if so, subsequent erosion has removed them. An important period of erosion certainly intervened between the Chico and the Miocene, and it is probable that the Eocene shore line was situated somewhere between the first foothills and the Marysville Buttes. This erosion has removed the greater part of the Chico sandstone, so that the Miocene along the valley border in part rests on older rocks, in part on fragments of Chico sandstone. While remov-

ing much of the Chico this Eocene erosion did not cut deeply into the underlying older series of crystalline rocks. Certain of the lower auriferous gravels underlying the Ione formation near the valley border may be Eocene or early Miocene, and the same age may be assigned to the deep gravels of the upper stream courses.

The early Miocene period.—About the time of the upper Eocene or the lower Miocene, then, the shore line had retreated far westward; this is directly indicated by the occurrence of heavy stream gravels brought up by volcanic agencies in the Marysville Buttes along with estuarine Miocene beds, correlated with the Ione formation. These gravels carry comparatively coarse gold. The slope of the Sierra had assumed the topographic character which the Miocene and Pliocene deposits have preserved for our inspection. The foothill topography of this old eroded surface consisted of comparatively rough ridges, the level tops of which indicated the old Cretaceous peneplain. The middle slopes consisted of broad, partly longitudinal valleys and comparatively gentle slopes in which the old peneplain is noticeable only in places, such as Banner Hill, Oregon Hill, Osborne Hill, and the tops of the hills of the upper Georgetown divide. The upper slope reaching up the divide, situated very nearly where it is today, on the west side of Lake Tahoe, consisted of rougher and deeper valleys, divided by more or less level ridges, indicating the old Cretaceous peneplain. English Mountain, the Black mountains, Snow Mountain, Duncan Peak, Granite Chief, indicate this Cretaceous peneplain in Nevada and Placer counties; Mt. Tallac, the Pyramid Peak range, Robb's Mountain and many others indicate the same in El Dorado county. The relation of the two eroded surfaces, the Cretaceous and the Miocene, is clearly discernible from any point in the lower foothills looking up toward the summit of the range. Above the deep canyons of the modern gorges extend the broad, flat lava plateaux capping the separating ridges and looking very much like an old base level. These lava flows cover the comparatively gentle topography of the Miocene valleys. Above them rise the peaks

and ridges just mentioned, and indicate with their level sky line the extend of a far older eroded surface, uplifted and dissected long before the auriferous gravels were deposited or the lava flows extruded.

The later Miocene period (*the Ione formation*).—This is the period of the auriferous gravels *par excellence*. Stream gravels had already formed to some extent in the lower reaches and deepest parts of the river valleys, but the greatest masses were accumulated during this period.

The shore line again moved eastward up to an elevation of at least 400 feet above the present sea level and a heavy series of sediments was laid down along the foothills which rose with decided relief above the waters of the gulf; this may be referred to as the Ione transgression. Only in the northern and middle part of the range did the gravels attain their maximum depth. One of the probable causes leading to their deposition has been indicated by Mr. J. S. Diller,[1] who holds that disintegration exceeded transportation at the close of the Eocene and beginning of the Miocene, and that consequently the surface was covered with a deep mantle of decomposed material; during the Miocene a slight uplift increased the erosive power of the streams and swept the detrital matter into the river courses. This is very probably a correct explanation, although perhaps not the only one. It seems that the steep foothill ranges may have acted the part of barriers restraining the gravels in the valleys of the middle slopes. To this the heavy accumulations along the American and Yuba River on the middle slope is in part due.

Close of the Miocene; beginning of the Pliocene. The eruption of rhyolite and andesite near the crest of the range closed the gravel period. At some time during the volcanic period, probably in the interval between the rhyolitic and the andesitic flows, occurred a new break along the eastern base of the Sierra. The principal movement in this latitude took place along the old fault-line extending from Verdi, Nevada (ten miles west of Reno), down towards Markleeville, while along the fault-lines

[1] 14th Ann. Report U. S. G. S., p. 427.

on both sides of Lake Tahoe little or no movement seems to have taken place. Near Verdi the displacement was probably smaller than further south. There is, along the first line, excellent evidence of the amount of the displacement. It probably did not much exceed 2000 feet, while the aggregate amount of both the late Cretaceous and the Miocene displacement is about 5000 feet near the latitude of the little town of Genoa, south of Carson. The best evidence of this displacement is found in the drainage of the West Fork of the Carson River, which from a meandering course in Hope Valley, in Alpine county—the topography of which accurately represents the pre-volcanic Miocene surface—breaks through the eastern scarp in a wild canyon of extremely steep grade, to again resume its meandering course in the Carson Valley 2000 feet lower.

Near the crest the range is at many places, as first pointed out by Dr. G. F. Becker,[1] intersected by a system of joint planes on which small movements have taken place, which may aggregate to considerable amounts. These joint systems, which probably were produced about the close of the Neocene, appear to accompany and supplement the large normal faults at the eastern base.

To sum up, the topography about Lake Tahoe has remained similar to its present form probably since the close of the Cretaceous, while a late Miocene or Pliocene fault of 2000 feet has been formed along the east side of the buttress lying to the east of Lake Tahoe. The displacement here indicated is less by several thousand feet than that shown by the grade of the Neocene rivers as outlined in a previous paper; this strengthens the belief that we have here to deal with a composite movement, one upward affecting a large area, and one downward consisting of local sinking of moats. In comparing this region with that north of 39° 30′ it should be borne in mind that, according to the best evidence, the northerly part during the gravel period stood at considerably lower elevations than the section about Lake Tahoe, as indicated among other things by the absence of

[1] Bull. Geol. Soc. Am., Vol. II, pp. 49–74.

gravels at the latter vicinity and the abundant occurrence of them northward. The relative post-Miocene uplift has consequently been larger northward. During the gravel period a drained lake probably occupied the Tahoe-Sierra Valley moat. During the volcanic period Tahoe became separated from Sierra Valley by masses of andesite. Separate lakes covered Sierra Valley, the Boca-Truckee Valley, Tahoe and Mohawk valleys. Carson Valley east of the Genoa buttress was also occupied by a lake during the volcanic period, as was the vicinity of Verdi and Reno. During the tilting of the Sierra Nevada that crustal block did not act as a rigid mass, but was slightly deformed and arched, as indicated from a study of the Neocene river grades.[1]

Along the western foot of the range a retreat of the shore line occurred during the andesitic eruption as indicated by the unconformity separating the andesitic beds from the Ione formation and by another dividing the Pleistocene from the Ione and the volcanic beds.

The Pleistocene period.—The last andesitic flows are supposed to mark the close of the Pliocene in the Sierra Nevada. This is a somewhat uncertain line as to its exact age, but it is the only one which can be drawn without creating artificial distinctions. It is true that in referring the Ione formation to the Upper Miocene and drawing the line between the Neocene and the Pleistocene at the close of the tuff and breccia flows, the line limit allotted to the Pliocene becomes somewhat restricted, the volcanic period, as above observed, being of comparatively short duration. It is not improbable that the earlier part of the Pleistocene of the Gold Belt maps includes some of the Pliocene as outlined at other localities in the United States. The Pleistocene of the Gold Belt maps includes one long period of extremely active erosion, chiefly characterized by canyon-cutting; during this time another advance of the shore line took place; the Great Valley being at this time a lake, the highest elevation of whose shores, well marked by bodies of gravel, extended 400 feet above

[1] Two Neocene Rivers, Bull. Geol. Soc. Am., Vol. IV, p. 297.

the present sea level. Mr. L. F. Ransome[1] has expressed a belief that the Great Valley during the early Pleistocene was chiefly above water, though transient lakes might have existed. An extensive acquaintance with the formations along the Sierra foothills can hardly fail to convince anyone of the reality of the Pleistocene body of water extending up to the level indicated, though for the later part of the Pleistocene after the drainage of the lake by the subsidence of the region about San Francisco,[2] Mr. Ransome's view is probably correct. A subsidence of only 50 feet would at the present time create a very large lake in the valley.

During the earlier and middle Pleistocene many minor eruptions of basalt took place, chiefly near the crest of the range. Lake Tahoe had first been dammed up by andesite during the latter part of the Neocene and during the earliest Pleistocene, its outlet, the Truckee River, cut a canyon through the andesite and through the northern continuation of the great buttress east of the lake. In middle Pleistocene time this canyon was again dammed up by a basaltic eruption, and again the lake cut an outlet through this second dam.

The second division of the Pleistocene period comprises the glaciation of the High Sierra, the drainage of the lake of the Great Valley and corresponding formations of fluviatile deposits.

During the glacial period the whole crest-region of the Sierra was covered with a continuous sheet of ice, *névé* and snow from which glaciers extended down along the principal river courses. The glacial basins were swept bare, the morainal débris accumulating at lower elevations, around the projecting ice tongues. The block east of Lake Tahoe and in fact the whole eastern slope was only glaciated to a small extent. The outlet of Lake Tahoe, the canyon in andesite between Tahoe City and Truckee City, has apparently never been filled with glaciers though ice streams from lateral canyons reached it in one or two places. Lake Tahoe does not appear to have been filled with glacial ice at any time.

[1] Bull. Dept. Geol. Vol. I, No. 14, p. 386.

[2] Cf. A. LAWSON, Univ. Calif. Bull. Dept. Geol. Vol. I, No. 8, p. 266.

The largest glaciers were found on the headwaters of the Yuba and the American rivers. The lowest elevation at which glacial traces have been found on the western slope is about 3500 feet. The third period, the present, is marked by the disappearance of the glaciers and by the continued formation of fluviatile deposits in the Great Valley.

It is not believed that, during the early Pleistocene any marked orographic changes took place along the eastern base of the Sierra. In very recent times—after the glaciation—a renewed faulting is noticeable at many places, such as at Owen and Mono lakes and near Genoa south of Carson, Nevada. At the later place the displacement is about 40 feet. Very strong springs, many of them hot, are located along the foot of the scarp, which is extremely sharply marked. As at Mono Lake[1] the deepest depression—here the Carson River—closely hugs the escarpment for considerable distance in spite of the active erosion and the large amount of material transferred to the valley from the escarpment. This appears to be a strong argument in favor of the view that the eastern block—the Carson Valley—is sinking, instead of the western block—the mountain scarp—rising.

The similarity of these conditions with those at the foot of the Wasatch, so admirably described by Mr. G. K. Gilbert, certainly appears very striking.

Recently Mr. F. L. Ransome has published an interesting criticism of the theory of isostacy as applied to the interior valley of California,[2] in which he arrives at the conclusion that the facts do not support the theory, in the case of the Great Valley, a conclusion which appears well justified. Mr. Ransome's argument could, however, have been made much stronger. From the above, it is clear, that there have been at least three important transgressions separated by unconformities, representing periods of erosion, since the end of the Cretaceous. The rivers sometimes extended far into the valley, while at other times the

[1] I. C. RUSSELL, U. S. G. S., 8th Rep., pp. 261–394.

[2] Univ. Calif., Bull. Dep. Geol., Vol. I, No. 14, pp. 371–428.

shore line moved far eastward. Subsidence has certainly not kept equal pace with deposition in the Great Valley.

CORRELATION WITH THE BEDS OF THE COAST RANGES.

In a recent bulletin of the Geological Department of the University of California, Professor Lawson has described the Miocene, Pliocene, and the Pleistocene from various points along the coast, calling especial attention to the evidence of recent elevation as attested by the numerous beach lines at elevations up to 1200 feet.[1] He has further described the Merced series from the San Francisco peninsula and the Wildcat series from the northern coast, identifying both as Pliocene, and deposited during the gradual subsidence of the coast preceding the recent uplift, marked by the beaches. He finds that the Miocene, as represented by the Monterey series is distinct from the Pliocene as represented by the Merced formation, and that the latter is separated from the former by a long period of depression. The Pliocene and the Pleistocene gradually merge into one another, and the somewhat arbitrary line between the two should be drawn at the upper part of the Merced series at a time when the shore line began to recede westward. In short,

[1] Bull. Dept. Geol. Univ. of Calif., Vol. I, No. 4, p. 148. Professor Lawson, in demolishing Professor Davidson's view of the beaches along the coast of California as formed by ice action, states that the only geologists who have observed and correctly interpretated them are Dr. Cooper (Geol. Cal., Vol. I, p. 184), in his observations on San Clemente Island, and A. Bowman, in describing the coast in the vicinity of San Francisco (Proc. Cal. Acad. Sci., July 1, 1872). This is evidently not quite correct. No geologist could for a moment mistake those beach lines, so plainly are they indicated, and we find, for instance, that W. P. Blake (Pac. R. R. Rept., Vol. V, p. 187) recognized a raised beach 300 feet above the sea at Monterey, and a general elevation of the coast. Dall found evidence of a post-Pliocene uplift of 600 feet in the vicinity of San Diego (Proc. U. S. Nat. Museum, 1878, Vol. I, p. 3). Mr. G. F. Becker recognized a recent elevation of the coast of at least 250 feet (Monograph XIII, U. S. G. S., p. 207) on the Sonoma coast. In 1888, in a paper on the Geology of Baja, California, by W. Lindgren (Proc. Cal. Acad. Sci., 2d ser., Vol. I, Part 2, p. 179) the terraces are referred to as follows: "The numerous oscillations of the shore line during post-Pliocene time are equally plain in Lower California, as along the coast north of it. . . . . The ancient shore lines are shown on Punta Banda (60 miles south of the Mexican line) as often well marked wave-built terraces;" four beaches were recognized, the highest at an elevation of 600 feet.

the history of the coast ranges in later geological times would be as follows:

Miocene depression.
Post-Miocene uplift and long period of erosion.
Pliocene depression; filling of valleys and truncation of the mountain to an approximate peneplain; archipelagic coast line.
Pleistocene uplift; beach lines.

The age of the beds has been determined by their molluscan remains, a line of evidence not altogether satisfactory where Tertiary and recent beds are concerned as has been pointed out among others by Professor Lawson[1] and also by Professor W. H. Dall.[2]

The question now arises how the beds along the foot of the Sierra Nevada should be correlated with the beds of the coast ranges. Dr. Lawson, without hesitation, correlates the Merced series with the auriferous gravels of the Sierra Nevada,[3] accepting Whitney's determination of them as Pliocene.

It has been shown in the preceding pages that the upper part of the ante-volcanic auriferous gravels correspond to the Ione formation, and both have on palæobotanic grounds been referred to the upper Miocene. It has also been shown that the flora of the volcanic period very closely resembles that of the Ione formation. A very similar flora has been described by Lesquereux from Corral Hollow and Kirker Pass near Mount Diablo, on the western side of the valley.[4] The beds rest in apparent conformity on Miocene carrying *Ostrea titan* Conrad, are associated with molluscan forms determined by Gabb as Pliocene from the twenty-one species identified; and are capped by detrital andesitic beds.

The characteristic feature of this flora of the Ione and the auriferous gravels is that it is related in its general characters to that of a subtropical moist region analogous to the northern coast of the Gulf of Mexico. It contains genera such as

[1] Bull. Dept. Geol. Univ. Calif., Vol. I, p. 57.
[2] Bull. 84, U. S. G. S., p. 195.
[3] Bull Dep. Geol. Univ. Calif., Vol. I, No. 4, p. 157. See also Vol. I, No. 1, p. 56.
[4] H. W. TURNER, Geol. Soc. Am. Bull., Vol. II, pp. 383–402.

Quercus, Ficus, Juglans, Magnolia, Persea, Laurus, Cinnamomum, Paliurus, Zisyphus, etc. Contemporaneously with this flora the salt water extended eastward as far as Mount Diablo and northward probably as far as the Marysville Buttes.

There are some remains of plants in the Merced series, described by Professor Lawson.[1] At the very base rests, on Mesozoic volcanic rock, a stratum of partly carbonized forest material from which abundant pine cones were collected; these were determined by Professor E. L. Green as *Pinus insignis* (Monterey pine), a species not widespread at the present day, but still growing abundantly dear Monterey; about the middle of the series little altered trunks of trees occur associated with cones determined as *Pseudotsuga taxifolia* (Douglas spruce), a species common in California at the present time. It is scarcely permissible to correlate these two floras. In the auriferous gravels there is not one species, according to Professor Knowlton, which can be undoubtedly identified with living forms, and moreover, the coniferæ are sparingly represented. Even conceding the possibility of a slightly cooler climate on the immediate seacoast, Professor Knowlton[2] does not believe that these two different floras could have existed at the same time and in so close proximity to each other.

The correlation of the Merced and Wildcat series with the auriferous gravels does not then appear permissible. It seems that in the maps of the valley border of the Sierra Nevada, the arbitrary line between the Neocene and Pleistocene has been drawn considerably lower than the similar arbitrary line established by Professor Lawson at the top of the Merced series. In other words the Pleistocene as defined on the gold belt maps, occupies a considerably longer time than the Pleistocene on the coast as defined by Professor Lawson. The Merced series is probably contemporaneous with the early Pleistocene of the valley border.

A detailed examination of the western valley border in the vicinity of Corral Hollow and Kirker Pass would greatly eluci-

[1] Bull. Dept. Geol. Univ. Calif., Vol. I, No. 4, pp. 143, 144.

[2] Oral communication, February 1896.

date the question. Stratigraphic, floral and faunal evidence should as much as possible be considered together to obtain correct results.

SUMMARY OF POST-JURASSIC GEOLOGICAL HISTORY.

Cretaceous	Basic eruptions along foothill volcanoes, continued from the Jurassic period.
	Folding of the Mariposa beds.
	Intrusion of granitic and dioritic batholites.
	Pre-Chico erosion, continued to approximate peneplain.
	Pre-Chico uplift and break along eastern edge. First differentiation of the Sierra Nevada.
	Sinking of the Tahoe-Sierraville moat.
	Dissection of the uplifted peneplain.
	Chico transgression.
Eocene	Retreat of Shore line; Téjon erosion along valley border and gradual degradation of the Cretaceous peneplain.
Miocene	Miocene (Eocene?) deep gravels.
	Heavy Bench gravels. Ione transgression along valley border.
Miocene?	Rhyolitic eruptions and continued accumulation of gravels.
Pliocene?	Late Neocene uplift and faulting along the eastern edge of the range.
	Retreat of shore line; short but active period of erosion.
Pliocene	Principal andesitic eruptions; lakes in the Tahoe-Sierraville depression and along the eastern slope.
Pleistocene	Early Pleistocene lake in the Great Valley and very active dissection of the uplifted Miocene surface.
	Basaltic eruptions.
	Glaciation and lakes along the eastern slope.
	Gradual retreat of the glaciers and lakes.
	Recent breaks along eastern fault-line. Fluviatile deposits in the Great Valley.

WALDEMAR LINDGREN.

THE ANORTHOSITES OF THE RAINY LAKE REGION.

A NUMBER of eruptive masses rising through the Keewatin (Huronian) schists and schist conglomerates of the Rainy Lake region in western Ontario were mapped and described by Professor A. C. Lawson in 1887, the most interesting group of eruptives occurring along the southern shore of Seine Bay and between Bad Vermilion and Shoal lakes, just to the east.[1] Here very basic and very acid rocks are found associated. The acid members of the group, quartzose granites containing much plagioclase, have been studied somewhat carefully from the fact that they contain important gold-bearing veins, but the barren anorthosites have been neglected. The soda granites, which often weather into the greenish sericite variety, protogine, and have been sheared and metamorphosed into sericitie schists near the quartz veins, have been described by Winchell and Grant[2] and the present writer,[3] and need no detailed mention here. The basic rocks of the group, briefly described as saussuritic gabbro by Lawson, but afterward identified by him as anorthosite,[4] deserve some further mention.

The largest area of anorthosite encloses the southern arms of Bad Vermilion Lake, and surrounds or is bordered by three areas of eruptive granite. Two or three miles to the west, on Seine Bay, a series of points and islands of anorthosite extend, with some interruptions, westward along the southern shore of the bay for about ten miles. The rock is generally white, almost like crystalline limestone, with only a very small proportion of darker minerals occupying spaces between more or less perfect phenocrysts of plagioclase which range in size from a

[1] Geol. Sur. Can., Part F, 1887, pp. 56 and 99.

[2] WINCHELL and GRANT, Geol. Nat. Hist. Sur. Minn., 23d Ann. Rep., pp. 58–60.

[3] Ontario Bureau of Mines, 1894, p. 89.

[4] Geol. Nat. Hist. Sur. Minn., Bull. No. 8, 1893, 2d part, p. 7.

quarter of an inch to a foot in longest diameter. Towards the western end of Bad Vermilion, however, there are points where the green constituent becomes more important, and the rock may be called a porphyritic gabbro.

Frequently portions of chloritic or sericitic schist have been enclosed by the anorthosite, showing its post-Keewatin age; and occasionally a green massive rock, apparently weathered diabase, is seen, probably portions of massive Keewatin rocks swept off by the molten anorthosite.

The rock, though clearly an anorthosite, presents some points of difference from the typical rocks of the name, so well described by Dr. Adams from the province of Quebec, the feldspars being always white, never purplish in color, and comparatively rarely showing the sheared and granulated character so often found in eastern Canada.[1] The marked tendency toward idiomorphism in the feldspars is apparently unusual in other regions. The loss of the purplish color is no doubt the result of weathering, which has generally progressed rather far, though cleavage surfaces showing twin striations can be found generally. The freshest example studied comes from a hill at the mouth of Seine River.

In the numerous thin sections examined more than nine-tenths of the rock is seen to consist of plagioclase, usually sprinkled with zoisite particles or more or less completely changed to a saussuritic mass. The darker portions lying here and there in angles between the feldspars consist mainly of a fibrous or scaly mineral with parallel or nearly parallel extinction and low double refraction, probably serpentine, but perhaps a member of the chlorite group. Augite was found as a remnant only once, and then was not of the diallage type. No other primary minerals were observed, not even magnetite; and very few secondary ones require to be added to those mentioned, only epidote, probably some albite, and a very little calcite. The feldspars, where fresh enough to study, show broad

[1] Ueber das Norian, Separat Abdruck, Neues Jahrbuch für Min., Beilageband VIII; and Can. Rec. Science, Vol. VI, No. 4, p. 190.

twinning according to the albite and frequently also the pericline law, the former ranging in angle of extinction from the twin plane between 17° and 37°. The average extinction angle in thin sections from Bad Vermilion Lake is about 24°, and from the mouth of Seine River 32°. The former feldspar is therefore bytownite and the latter anorthite, both more basic than that of the typical anorthosite, which Dr. Adams finds to be labradorite.

In the freshest section studied (783, mouth of Seine River) the large interlocking feldspar individuals often show a thin band of fresh, clear feldspar where one joins the other; and this clear feldspar strip is seen, when examined with a high power, to form a secondary enlargement of the adjoining crystals, the twin striations running out into it. The extinction angles of these secondary feldspar rims vary from 8° to 14°, corresponding to labradorite, so that the later feldspar is more acid than the older. In one case a bytownite crystal has been broken, the parts slightly shifted, and then cemented with labradorite, most of the twin lamellæ running across the strip of cement.

An analysis of a specimen from the mouth of Seine River was made by Mr. William Lawson in the laboratory of the School of Practical Science, Toronto, the results being given in column No. I. In No. II an analysis of anorthosite from Rawdon, Que., made by Sterry Hunt and quoted by Dr. Adams is given for comparison.[1] No. III gives the results of an analysis of granite adjoining the Bad Vermilion anorthosite area, and is the work of Mr. Lawson.

	I	II	III
SiO_2	46.24	54.45	76.20
Al_2O_3	29.85	28.05	14.41
Fe_2O_3	1.30	0.45	....
FeO	2.12	....	1.49
MnO	trace	....	....
CaO	16.24	9.68	2.19
MgO	2.41	....	0.65
Na_2O	1.98	6.25	3.32

[1] Ueber das Norian, p. 494.

	I		II	III
K_2O	0.18		1.06	2.44
Co_2	1.03	(H_2O)	0.55	....
	101.35		100.49	100.70
Sp. Gr.	2.85		2.69	2.65

The low percentage of silica and soda, and the high percentage of lime as compared with the anorthosite from Quebec are notable and correspond to the results of microscopic examination, the specimen from Seine River consisting chiefly of anorthite, and that from Rawdon of labradorite. The specific gravity, 2.85, is very high, perhaps because of the presence of considerable zoisite. The specific gravity of a specimen from Bad Vermilion Lake was determined to be 2.76, corresponding to its slightly more acid character, since it consists of bytownite.

The results of the analysis show that the anorthosite from the mouth of the Seine is one of the most basic of the massive rocks, having about 8 per cent. less silica than the typical rocks of eastern Canada, but it is probably wiser to include it among the anorthosites, since the somewhat more acid rock from Bad Vermilion Lake links it to the eastern ones.

It would perhaps be most logical to name the whole series of rocks consisting essentially of plagioclase anorthosites or plagioclasites,[1] adopting a binomial nomenclature like that tacitly admitted in the classification of other rocks, such as the granites. We should then speak of anorthite, bytownite, and labradorite anorthosites or plagioclasites; and the list might require to be extended to include andesine and oligoclase rocks, perhaps also albite rocks. The albitites described by Turner from California, under the head of syenites, are dike rocks apparently and should perhaps not be classed with the plutonic rocks referred to here.[2] The name anorthosite has priority but has a very tautological sound in the term describing the rock just discussed, anorthite anorthosite.

Lawson looks on the anorthosite and granite areas of Bad

[1] See Viola as quoted by Rosenbusch in Massige Gesteine, Erste Hälfte, p. 298.

[2] American Geologist, June 1896, p. 379, etc.

Vermilion Lake as representing the truncated base of a Keewatin volcano which served as one of the vents for the pyroclastic materials so widely found in the Keewatin rocks of the region, the basic rock coming first and the acid afterwards.[1] In this he is probably not correct, for there is good evidence to show that the anorthosite, which probably solidified under a considerable thickness of superincumbent rock, was so far exposed by denudation that fragments of it could be rolled into bowlders and become part of a conglomerate before the eruption of the granite. The latter rock has sent apophyses into the anorthosite and has pushed its way through a schist conglomerate containing pebbles and bowlders of quartz-porphyry, sandstone, green schist and occasionally also anorthosite quite like some facies of the adjoining mass. Apparently a long interval separated the anorthosite eruption from that of the granite. The sharp segregation of a magma into a basic anorthosite and a very acid granite would in any case be rather surprising.

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[1] Geol. Sur. Can., loc. cit.

THE MECHANICS OF GLACIERS. I.[1]

1. *Law of flow.*—If we consider the ice flowing through two cross-sections of a glacier, it is evident that for a glacier in equilibrium, that is, one neither increasing nor diminishing in size, the quantity flowing through the lower section must equal that flowing through the upper one diminished by the quantity melted between them, if we are in the region of melting (the dissipator); or increased by the quantity of ice accumulated between the sections, if we are in the region of accumulation (the reservoir). Keeping the upper section at the névé-line and moving the other one down the glacier, the melting area between the sections increases and therefore the flow through the lower section becomes less. Now placing the lower section at the névé-line and moving the upper we see that the amount of accumulation between the sections increases, and consequently the flow through the upper section diminishes, as we move it higher up the reservoir. If we keep our two sections at a fixed distance apart, and move them to different parts of the glacier, the difference of the flow through the sections must increase as we go down the dissipator, because the rate of melting increases, and must increase as we go up the reservoir because the accumulation increases. We can say then that *the greatest flow occurs through a section at the névé-line and diminishes as we go up or down the glacier from there*; and, moreover, that *the rate of diminution of the flow becomes greater the further we go from the névé-line*. This is the *law of flow*, and is perfectly general; it depends only on the law of the indestructibility of matter, and the observed facts that the ice of glaciers moves, and that there is accumulation above, and dissipation below, the névé-line.

The steeper the dissipator's slope the more rapidly will the

[1] Read before the Geological Society of America, at the Philadelphia Meeting, December, 1895.

rate of melting increase as we go down the glacier, and the more rapidly will the flow diminish; similarly, the steeper the reservoir the more rapidly in general will the flow diminish as we ascend.

It has been stated as an empirical rule that the velocity of the ice of glaciers lying in beds of uniform slope is greatest in the neighborhood of the névé-line and diminishes as we leave it going up or down the glacier. This rule is, like most empirical rules, subject to exception, and may be stretched beyond its limit, as when Professor Heim (Gletscherkunde, p. 160) attempts to account for the increased velocity near their ends of some Greenland glaciers which break off in bergs, by saying that we have here to do with only the upper part of the glacier; whereas, in reality, the ends are some distance below the névé-line. The general law that the flow is less below, than at, the névé-line must hold; this flow equals the product of the average velocity by the sectional area by the effective density. The more rapid surface velocity is permitted by the formation of immense crevasses which reduce the effective density of the upper 200 feet of the ice by perhaps a half. The real and sufficient cause of this increase in velocity is the lack of support in front, which Professor Heim also describes. The flow near the end of such glaciers is not as large as appears at first sight; it is only the upper part of the ice that has such an abnormal velocity; the lower part, being supported by the pressure of the water, must have a velocity not differing very greatly from what it would have if the glacier completed its course and ended as an ordinary alpine glacier. Indeed, as the increasing velocity at the surface is only permitted by the opening of immense crevasses, so an increasing velocity in the middle and under part of the glacier would also be accompanied by similar openings; and the whole body of the ice would be so torn by these great fissures, that comparatively thin sheets would be broken off from the glacier's end, and large icebergs could not be formed. The drag of the upper layers over the lower ones, would, in glaciers whose ends are floating, have to be entirely

balanced by the cohesion of the lower ice-layers, as there is no friction against its bed.

The empirical rule does not cover the case of a glacier like the Mer de Glace, where the bed becomes steeper near its end, causing a more rapid motion. But the law of flow must hold; here again the effective density of the ice is reduced by the opening of wide crevasses, and the sectional area is undoubtedly less than it would be if the slope of the glacier's bed continued uniform.

In the case of glaciers with beds of uniform slope, the velocity and flow increase and decrease together, though not in the same proportion.[1] If we had a glacier of indefinite length and of uniform section, it is evident that the direction of flow would be parallel with the slope, and the velocity along any line parallel with the glacier's axis would not vary as we move along the direction of flow. To calculate the forces acting on a section of such a glacier we have only to consider the weight of the section, the viscosity of the ice and the friction against the bed. The motion consists of two parts: (1) the sliding on the bed, of which we have hardly any knowledge; (2) the shearing of the section by virtue of which $A\,B$ (Fig. 1) would be deformed into $A'B'$. Let us call the velocity of a point under such conditions the *normal velocity* corresponding to that particular form and size of the cross-section.

A glacier of uniform section could not exist if there was any melting; for we have seen that in this case the flow would become smaller as we go down the glacier, and with uniform section this would require a decreasing velocity, which, however, is not admissible; for, from the supposed uniformity of the glacier, every section would be subject to the same forces and would move with the same velocity. Therefore, the slope of the

[1] The remainder of this section and all of the next are based on the theory that the ice of glaciers acts in general like a viscous substance, and that the sole cause of the motion is the weight of the ice itself. I am not discussing the physical nature of ice which gives it this viscous property. Similar conclusions might be reached on other theories. The rest of the paper is only dependent on the observed phenomena of glaciers.

glacier being uniform, wherever there is melting the cross-section must change so as to produce a smaller flow as we descend the glacier. For glaciers which fill narrow valleys this simply means a diminution in both the breadth and thickness of the glacier; but for those which spread out, like the Davidson glacier in Alaska, the flow is diminished by the smaller thickness, in spite of the increased breadth.

We may infer a similar thinning of the glacier above the névé-line; indeed, with many glaciers, the great breadth of the reservoir, notwithstanding the smaller density of the ice, requires a very small depth in order that the flow should not be too great.

If we look upon the ice-sheet, which covered North America, diagrammatically as radiating from a center, and suppose that the annual accumulation and melting per unit surface were proportional respectively to the distance inside and outside of the névé-line, we find, in order that total melting and accumulation should be equal, that the névé-line would have been at about two-thirds of the distance from the center to the circumference of the circle. It is probable, however, that the melting was larger at the edge, and the accumulation less at the center than this, and, therefore, that the névé-line was nearer the circumference. The greatest flow was of course through a section through the névé-line, and the greatest velocity must have been somewhere in the same neighborhood.

Pressure.—Let us see if the different parts of a glacier, gradually thinning out to its ends, can have the *normal velocities* due to their cross-sections. We know next to nothing about the sliding of the ice over its bed, but we are safe in assuming that the normal velocity of sliding would be no greater in a thin than in a thick section.[1]

Consider then that the bottom velocity of the region between the two sections *AB* and *CD* of the dissipator is uniform (Fig. 1). For the sake of simplicity we will consider the thickness of the

[1] The only experiments bearing on this point are those of HOPKINS (*Phil. Mag.*, London, 1845, Vol. XXVI, pp. 3–6). By means of a wooden frame he held together a

glacier small in comparison to its breadth. After a certain time the sections would be deformed to $A'B'$ and $C'D'$, if the ice moved everywhere with its normal velocity. The slope of the deformed section at any point would depend only on the weight of the ice above that point, *i. e.*, on its depth below the surface of the glacier, and therefore the form of the section $C'D'$ would be exactly the same as that of the upper part of $A'B'$. As the

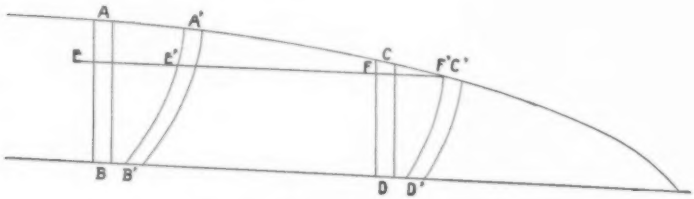

FIG. 1. Displacement of sections by flow.

slope of $E'B'$ is greater than that of $F'B'$, it is evident that more ice would enter through EB than would leave through FD in the same time, EF' being parallel to the bed of the glacier; but this is impossible under the supposition of normal flow, for we have only considered a part of the glacier below the surface, where no melting takes place.[1] The tendency of the thicker sections to move faster than the thinner ones, at the same distance from the bed, causes a forward pressure on the latter, increasing their velocity, and a backward pressure on the former, diminishing their velocity. The ice near the lower end of the glacier is thus under a pressure greater than the *normal pressure*[2]

number of pieces of ice on a slightly inclined rough sandstone slab, and found that the mass slowly slid down the slope with a uniform velocity approximately proportional to the pressure against the slab and to the angle of inclination, for angles between 1° and 10°. When the sandstone was smoothed but not polished a motion was observed at an inclination of forty minutes. The ordinary laws of the friction between solid bodies do not apply at all to the forces between a glacier and its bed.

[1] We here neglect the melting at the lower surface of the glacier which is so small as not to alter the argument.

[2] The normal pressure is the pressure which would exist if the glacier were of infinite length and uniform section.

and would therefore have a tendency to rise, would be squeezed up, so to speak.

We cannot reason very definitely about the pressure above the névé-line, for the much increased breadth of the reservoir, the smaller density of the ice and the possibly greater slope of the bed may result in either pressure or tension according to their relations to each other and to the thickness of the glacier.

The idea of a pressure on the lower reaches of a glacier due to the ice above has been generally held by glacialists, but I think without satisfactory reasons. It seems to have been inferred generally from the diminishing velocity of the lower parts of the glacier; but it is not due to this, for it is quite conceivable that by an increasing slope, and suitable melting, every section might have its normal velocity; there would be no effective pressure upon the upper regions, and there might still be a diminishing surface velocity.

Indeed, the extra pressure is not due simply to diminishing flow, but to the fact that the flow diminishes more rapidly than the cross-section. This may be stated in algebraic language by saying that the normal flow is not proportional to the linear dimensions of the section; it is not even proportional to the square of the linear dimensions, but probably to the third power.

In the dissipator of a circular ice-sheet, or of a spreading glacier, successive sections increase in breadth with a more rapid diminution of thickness than in the case of a linear glacier. This causes a considerable pressure of the rear on the forward sections, resulting in a more rapid radial movement of the ice than would occur without this pressure and in the opening of radial crevasses. It is not unlikely that such crevasses determined the positions of the eskers formed during the glacial epoch.

Direction of flow — Stratification. — In order that the general volume of the glacier should be preserved we must have below the névé-line, where there is melting, a component of the motion towards the surface, and this component is strongest where the melting is greatest, *i. e.*, it gets larger as we descend the dissipator. On account of the gradual thinning of the glacier this

condition would be satisfied if the motion were everywhere parallel to the glacier's bed, but we have already seen that on account of the pressure from behind there is really a small movement of the ice away from the bed. Above the névé-line this is reversed. Here there is accumulation; and, unless the reservoir continually increases in thickness, the motion must have a component downward into the glacier, and this component must be greater where the accumulation is greater, *i. e.*, in general as we ascend the reservoir. We can thus draw on the surface of the glacier the approximate directions of motion, and beginning at the névé-line, where, as there is neither melting nor accumulation, the motion must be parallel to the surface, we can connect these lines and have a diagram of the lines of flow in the whole body of the glacier (Fig. 2). The slight melting of the glacier in contact with its bed would produce a small component of the motion towards the bottom, and in the dissipator also towards the sides; but in the reservoir the accumulation results in a movement away from the sides. In picturing to ourselves the relative velocities of points at different distances from the surface, it is best to consider points lying in a section drawn everywhere at right angles to the lines of flow. The velocity of points in such a section will diminish as we approach the glacier's bed, on account of the friction which acts on the ice there. We can also show the positions assumed by the strata of annual accumulations. Perhaps the best way to do this is to follow the successive positions of a chosen stratum. At the end of the summer the snow deposited during the previous year will end in a thin wedge at the névé-line, and its thickness will at every point equal the corresponding annual accumulation. A year later the end of this stratum, with but small loss by melting, will have been carried a short distance down the surface of the glacier; and every point of the stratum following its proper line of flow, will have progressed down the valley and into the body of the glacier, and the stratum will have reached the position *2*. Continuing in the same way we can trace in a general way the position the stratum will have

in successive years; and these positions, at any one time, will correspond to those of successive annual strata.[1]

We readily see that the strata have a gentler slope than the lines of flow in the reservoir, but a steeper slope in the dissipa-

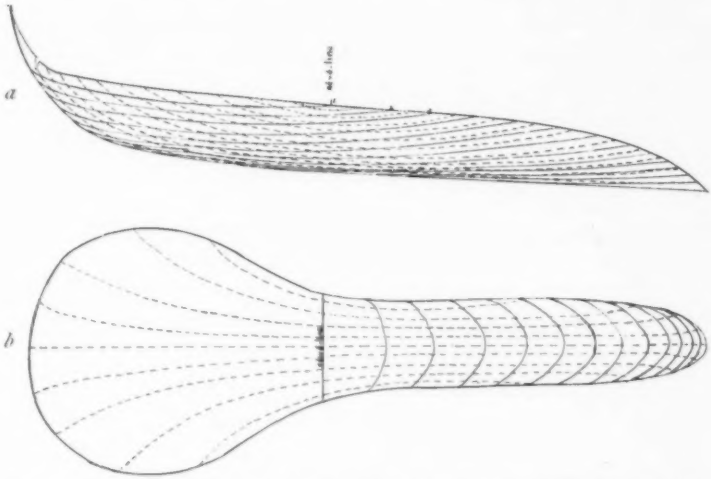

FIG. 2. Diagram of stratification (*a*), and lines of flow (*b*). Section and ground-plan.

tor; and that outcrops of strata can only occur below the névé-line.

The lower end of a new stratum is in the part of the glacier where the horizontal motion is greatest, and it never sinks far into the body of the dissipator, whereas, the upper end of the stratum originates in a region of small horizontal motion and later forms the lower layers of the glacier; the stratum, therefore, is stretched out and grows thinner on account of the differential motion, and also on account of the compression of the

[1] AGASSIZ (Syst. Glac., pp. 273–276) very nearly reached this conception of the disposition of strata and the direction of flow. Reverend O. FISHER (Phil. Mag., London, 1879, Vol. VII, pp. 381–393) presents somewhat similar ideas in connection with the stratification of Antartic ice. The theory presented above was developed before I was familiar with the latter's work.

snow into ice. During the first part of its course the angle which it makes with the bed of the glacier steadily increases; but later diminishes until probably it at last becomes nearly parallel with the glacier's bed.

It is to be noticed that the largest accumulation occurs under the mountain cliffs where the glacier receives, in the form of avalanches, much of the snow that falls on the slopes above. It is here then that the vertical component of motion is greatest, and it is also in this neighborhood that we find the *bergschrund;* which marks the line where the more rapidly moving ice below pulls away from the more slowly moving ice above. Reverend Coutts Trotter[1] has made the important suggestion that the *bergschrund* may mark the line above which the mean annual temperature is below freezing, and therefore the ice above it is frozen to the mountain, whereas, the ice below slides on its bed in addition to its shearing motion. Unfortunately, there is, so far as I know, no experimental evidence bearing on this point. Without disputing Mr. Trotter's idea, we see that the general theory leads us to expect a considerable change in motion in this part of the glacier; and when we recall that the surface slope diminishes rapidly below the *bergschrund*, we are driven to infer a rapid increase in the thickness of the glacier, and at least a large factor in the formation of the *bergschrund* becomes clear; for above it there is a thin coating of ice on the mountain slope, and below a much thicker mass of ice resting on an almost equally steep bed; and this would certainly result in a marked difference in velocity of the two parts.

Accurate observations on the direction of motion and on the stratification are few. Désor found at the side of the Unteraar glacier a motion of the ice having components down the valley, towards the side, and upwards.[2] Agassiz found by a line of stakes across the same glacier, whose positions and levels had been carefully determined, that during the winter the ice near

[1] Proc. Roy. Soc., 1885, Vol. XXXVIII, pp. 92–108. In this article Mr. Trotter describes some very instructive experiments showing that glacier ice will shear under very small forces if sufficient time is allowed.

[2] AGASSIZ, Système Glaciare, pp. 499–504.

the center of the glacier had suffered an upward displacement of 2.25 meters, and that the average upward displacement of the whole section was 1.4 meters.[1] These amounts are given after allowing for the natural thickening of the ice due to winter progression parallel to the glacier's bed, without melting. There is no apparent reason why the directions of flow in the winter and in the summer should differ; so I think these observations indicate a continuous movement of the ice toward the surface, as we should expect.

Professor Pfaff found in one of the reservoirs of the Aletsch glacier, where the surface slope was 9°, that the direction of motion made an angle of about 40° with the horizontal. This is certainly a high angle and Professor Heim does not think the method used sufficiently free of error to establish these "somewhat astonishing results."[2] Here again, however, the observations are in harmony with theory. It is unfortunate that so little has been done to determine the vertical component of the motion.

The correct observation of stratification is very difficult. It is next to impossible to determine the surfaces of separation of successive strata in the dissipator unless we find them marked by a thin layer of débris. Aggassiz has made a drawing of several such débris layers as they were exposed in a hole in the upper part of the dissipator of the Unteraar glacier.[3] These must be true surfaces of stratification; they dip up stream at an angle of about 30°.

Professor Russell has described débris layers in the Sierra Nevada glaciers, and suggests that they separate successive strata; they occur at fairly regular intervals, dip into the glaciers, and were only seen below the névé-line.[4]

When the junction of two glaciers, which gives rise to a

[1] Syst. Glac., pp. 559–563.

[2] HEIM, Gletscherkunde, p. 184.

[3] Syst. Glac., p. 260. Atlas Pl. V, Fig. 15.

[4] The Glaciers of the United States. 5th An. Rep. U. S. Geol. Surv., 1883–4, pp. 316, 319. Pl. XXXVII shows the outcrops of the layers in the Mt. Dana glacier. See also HEIM, Gletscherkunde, p. 131.

medial moraine, occurs in the dissipator, the moraine remains on the surface of the ice; but if the junction occurs in the reservoir the moraine is covered up by later strata of snow and reappears lower down in the dissipator; the further the junction is above the névé-line, the further is the point of reappearance of the moraine below that line. Rock material that falls on the snow from the cliffs in the cirque is carried by the flow along the under part of the glacier and reappears at the surface only near the lower end of the dissipator.

We have but few observations bearing on these theoretical inferences. In Agassiz's map of the Unteraar glacier one or two small moraines are shown as beginning on the surface of the ice some distance below the névé-line. And it is not at all unlikely that what is usually called the spreading of the moraines near the glacier's end is largely due to the appearance at the surface of the débris fallen on the glacier from the cliffs surrounding the reservoir. A glance at the lines of flow (Fig. 2) will make this clear.

The Gorner, the Findelen and the Zmutt glaciers, near Zermatt, end within a few miles of each other; the first two, originating on high snow-covered land surrounded by snow ridges, have a large portion of their surfaces comparatively clean to the end; the last, whose reservoirs are dominated by precipices from which rocks are continually falling, is entirely concealed at its lower end by débris. Of the tributaries of the Muir glacier in Alaska, Dirt glacier, originating in a cirque, has two or three miles of its lower end deeply covered by débris, whereas the White glacier, nearby, whose reservoir is not surrounded by cliffs, has ordinary linear moraines.[1]

The lines of flow (Fig. 2) explain why all observers have had practically unsurmountable difficulties in following the stratification from the reservoir through the dissipator.

The parts of the strata formed at a distance from rocky slopes have very little dust blown upon them, and consequently when they reappear at the surface in the upper or middle regions

[1] See Map in Studies of Muir glacier, Alaska, Nat. Geog. Mag., Vol. IV, p. 52.

of the dissipator the stratification is but slightly, if at all, indicated by dust bands. The strata should be well defined at the lower end, but the large amount of débris on the surface and in the crevasses, would make them difficult to recognize.

The débris in the lower layers of some glaciers may have a similar origin, and may not have been picked up from the ground beneath. Indeed, in general a downward rather than an upward motion probably occurs near the bottom, and some of the material forming the ground-moraine may have been originally dust or rock fallen on that part of the reservoir's surface, near the encircling cliffs, which afterwards formed the lower layers of the glacier. For, on account of the heat derived from the earth, two feet of ice would be melted from the glacier's under surface in a hundred years, and would deposit its débris under the ice.

Form of the glacier's surface.—For equilibrium the melting of the ice at every point of the surface must exactly equal the supply; this is the necessary condition; and since the upper layers move fastest, their melting must be fastest; this is brought about by the slope of the surface being least where the motion is most rapid, thus exposing to melting a larger surface of the layer. Or we may say that the angle between the direction of motion and the surface is greatest where the motion is smallest and the melting most active. At the end of the glacier, therefore, and near the ground, we find the slope steepest; and as we pass up along the surface of the ice the motion becomes faster and the melting less and consequently the slope diminishes. This also explains the rounded plan of the glacier's end and the depressed sides. If we knew accurately the distribution of velocity and of melting we could calculate the shape of the surface for equilibrium; but without this our approximate knowledge of these quantities enables us to see that the general form of the dissipator's surface agrees with the theory.

Glaciers are continually changing in size, so that the conditions for equilibrium can be looked upon as approximately

true only when the changes are small, or when an average is taken over a long period.

Form of the glacier's lower end.—Let us now give our attention to the lower end of the dissipator. We have seen that the surface slope at any point depends on the velocity and rate of melting at that point, and varies inversely with them. The general form will, therefore, depend on the differential velocity. (We are considering a portion of the glacier so small that we may suppose the melting uniform; though this would be somewhat modified by the direction of the sun's rays.) The larger the glacier, the greater in general will be the differential motion, and the more rapidly will the slope diminish as we ascend from the end. For very small glaciers the differential motion is small and the slope remains steep. If anything should cause an abnormally rapid melting of the lower layers, the natural slope could not be retained, but the upper layers would advance over the lower ones, project and break off. Professor Chamberlin[1] in his excellent descriptions and illustrations of the glaciers of northern Greenland has introduced us to just such forms. Fig. 3 is a section taken from one of Professor Chamberlin's photographs of Bryant glacier,[2] which is a good example of the type of glacier we are now considering. It is about 140 feet thick at the end; the lower layers, for something more than half its thickness, are full of débris; the upper ones are practically clear with an occasional layer of débris. The terminus of the glacier inclines slightly forward in the dirty lower layers, above which the clear ice projects in one or two somewhat overhanging vertical steps to the upper surface of the glacier, which slopes back from this point according to the natural surface of an alpine glacier. Wherever a débris layer occurs in the clear ice there is a reëntrant groove in the cliff, and the layer above overhangs. Wherever the layer of débris is interrupted so is the groove.

All indications show a very slow motion, which is probably entirely accounted for by the small thickness of the ice.

[1] This JOURNAL, Vols. II and III; Bull. Geol. Soc. Amer., 1895, Vol. VI, 199–220.

[2] Bull. Geol. Soc. Amer., 1895, Vol. VI, Pl. III, Fig. 2.

Professor Chamberlin has suggested that a partial cause of the vertical and overhanging ends is the greater effect of the nearly horizontal rays of the sun on the steep edges than on the sloping backs of the glaciers; this is undoubtedly a true cause; he thinks, however, it is not the whole explanation, but that there must be some special shearing at the débris-bearing layers.

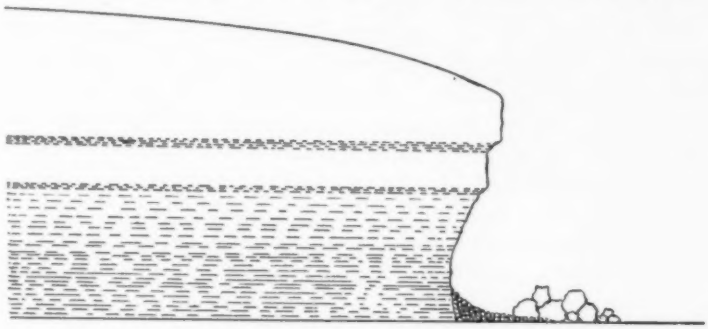

FIG. 3. Diagrammatic section of end of Bryant glacier.

This seems to me unnecessary; and Professor Russell[1] has lately made clear that the presence of débris in a glacier diminishes, instead of increasing, its power to shear.

The endings of these glaciers present a close analogy to the endings of tide-water glaciers. The lower layers of the latter have their extent determined by the equality between the rate of motion and the melting due to the salt water, and the upper layers project over them until they break off.[2] In these Greenland glaciers the extent of the lower layers depend on their rates of motion and of melting, and the upper layers push over them until they break off from lack of support, as is shown in the illustration referred to by the pieces of ice lying in front of the glacier. Above the vertical cliffs, thus produced, the ordinary conditions of melting prevail, and the surface of the glacier

[1] This JOURNAL, Vol. III, 823–832. The proof depends on the quasi-viscous theory of glacial movement.

[2] Studies of Muir glacier, Nat. Geog. Mag., IV, 47.

follows the ordinary alpine form. The débris is, however, an important factor in increasing the melting of the lower layers. It acts in two ways: it absorbs the sun's rays more abundantly than the ice does, and its presence reduces the effective density of the ice, so far as melting is concerned, just as air bubbles would. Its existence seems almost necessary for the development of overhanging ends, for there are glaciers in the same region which end like ordinary alpine glaciers;[1] and Professor Salisbury tells me that, so far as his observation went, all those, and only those, containing much débris in their lower layers, have vertical or overhanging ends well developed. Professor Chamberlin does not think this is universal.

Both of these endings are forms of stable equilibrium; for an increase of velocity, accompanied, as it must be, with an increase of differential velocity, would cause the upper layers to project more, resulting in more breakage; and the surface slope of the lower layers would overhang more, thus presenting a larger surface to the salt water or to the air, as the case may be, and increasing the melting; for we must remember that even in northern Greenland some of the melting comes from contact with the air, which, during the summer, is well above the freezing point.

Variations of glaciers.—Although the sloping surface of alpine glaciers is a surface of equilibrium, it is unstable, and any cause, such as a few years of greater melting or accumulation, which would alter this slope, would destroy the equilibrium, and the surface would tend to depart more and more from its equilibrium form. When the equilibrium of the surface is destroyed by diminished melting or increased flow, the upper layers everywhere advance over the under ones; of course, the higher and more rapidly moving layers advance at a greater rate, but as they are near the névé-line, where the direction of motion makes but a small angle with the glacier's surface, they cause but a very small swelling; nearer the end, however, the direction of motion,

[1] CHAMBERLIN, Bull. Geol. Soc. Amer., 1895, VI, 202. SALISBURY, this JOURNAL, 1895, III, 887–890.

making a higher angle with the surface, tends more directly to increase the thickness. This increases the velocity, causing a further departure from the equilibrium surface, and the glacier grows in length with a small increase of thickness in the reservoir, and with a great increase of thickness at its lower end. The ice is rapidly carried off until the upper part of the dissipator becoming thinner, there is a gradual diminution in velocity, and the end of the dissipator having advanced to warmer regions the melting is faster and the glacier begins to recede. This makes it evident that under certain conditions, such as a bed of increasing slope, a glacier, when once the equilibrium between its flow and melting is destroyed, might advance with strides entirely out of proportion to its usual motion, as has frequently happened with the Vernagt glacier.

A glacier having the equilibrium form corresponding to the climatic conditions prevailing at the time, would lose this form and respond immediately, by a change in length, to the slightest climatic change; whereas, a glacier widely removed from its equilibrium form could not respond by a change in length until the effects of the climatic change had accumulated sufficiently to bring the glacier back to, and carry it beyond, its equilibrium form. Two glaciers, in general similar, but differing in their exposure or slope, might be very differently removed from their respective equilibrium forms, and would therefore respond at different times to a given climatic change; indeed, one of them might be so far removed from its equilibrium form that a climatic change lasting for several years might not be long enough to reverse the condition of retreat or advance in which it happened to be.

Smaller glaciers in general respond more quickly to climatic variations, and we can see why this should be true; for, a change in the amount of snow-fall or of melting, would produce the same change in the actual thickness of two glaciers of different sizes, but subject otherwise to the same conditions. The smaller glacier would, however, experience a greater relative change in thickness, resulting in a greater relative change in flow; it

would therefore respond more quickly than the larger glacier; this is confirmed by observation. We should also expect a relatively greater change in size of its dissipator; although, from lack of data, I cannot say that this inference is borne out, still we know that many small glaciers entirely disappear after a few dry hot seasons, and reappear after a few cold wet ones.

This theory offers a connecting link between the theories of Professor Forel and Professor Richter.[1] According to it a glacier will respond to any climatic change, not by the progression of a wave along its surface, but by a change over the whole surface; but this change will not show itself by reversing the phase (the condition of advance or retreat) of the glacier until it has sufficiently accumulated to carry the surface up to and beyond its equilibrium form.

HARRY FIELDING REID.

[1] See this JOURNAL III, 278-288.

LOESS IN THE WISCONSIN DRIFT FORMATION.

Loess has long been known to cover the glacial drift of the earlier ice epochs at various points, especially along the water courses of the western portion of the Mississippi basin, and to have more or less extensive development in like relation to valleys in extra-glacial territory both west and south of the drift. It also occurs, especially along the Mississippi and its tributaries, in the driftless area which lies in Wisconsin, Illinois, Iowa, and Minnesota.

In addition to its occurrence at the surface over the older drift sheets, loess is known to occur between beds of till outside the area covered by the ice of the Wisconsin epoch. In some places the surface of this buried loess is marked by a soil, often of considerable thickness. These facts show that there are at least two sheets of loess connected with the earlier sheets of drift. The sheet of loess which overlies the Iowan drift often terminates abruptly, as a surface mantle, at the edge of the Wisconsin formation, but frequently passes beneath it. Outside the drift-covered country also there are, in some places, two distinct beds of loess, the one above the other.[1] The surface of the lower is often marked by a well-developed soil, and furthermore shows, by its color and chemical condition, that it was long exposed before the overlying mantle was deposited upon it.

The stratigraphical relations of the loess and drift, especially when taken in connection with other considerations, seem to point clearly to the conclusion that the loess had an intimate connection with the drift in origin, and that there were at least two epochs of loess deposition later than the first, and earlier than the last, glacial epoch. The uppermost bed of extra-glacial loess, where two are developed, seems to be capable of definite

[1] Geological Survey of Arkansas, Ann. Rep. 1889, Vol. II, p. 233.

correlation with that which overlies much of the drift of the Kansan and Iowan epochs, while the lower is presumably the equivalent of some or all the loess beneath the Iowan and above the Kansan drift.

Heretofore loess has not been known to occur in or above the drift of the Wisconsin epoch; but during the past summer it has been found in connection with this formation at several points in Wisconsin, namely, near Green Lake, Devils Lake, and Ablemans.

Loess near Green Lake.—Loess occurs in at least two localities near Green Lake, in Green Lake county. One of these points is about two miles northeast of the village of Dartford in the S. W. ¼ of Sec. 10 (Tp. 16, R. 13 E.), where the loess is worked as molding sand for brass foundries. The loess here was not seen to contain shells or concretions, and is calcareous only at its base, and there but slightly. Its texture is fairly normal. It is exposed to the depth of eight or ten feet. The loess at this point is between 150 and 200 feet above Green Lake, and near the crest of one of the many high ridges of the region, the summits of which represent an old base plain. Its substratum is till of the Wisconsin formation.

The other point where loess is found is at the west end of the lake in Sec. 4 (Tp. 15, R. 12 E.). The loess here is at a lower level, and on a slope which faces the lake. As in the other case, it overlies the drift of the Wisconsin formation. The loess at this second locality is of greater thickness than at the first, and is normal in texture, color, structure, and composition. It is calcareous, and has the roughly columnar structure which frequently characterizes loess exposed in vertical faces, and contains both the common types of gastropod shells, and calcareous concretions, though neither is plentiful. Its character is in every way such as to allow of no doubt of its being normal loess. Near its base it is interstratified with gravel.

The loess in the vicinity of Green Lake is of special interest, not only because of its association with the deposits of the last

glacial epoch, but also because its relations show, in at least one of the two localities, that it is not the work of wind.

Super-till loam about Green Lake.—All about Green Lake it is a striking fact that the till, and indeed the drift in general, is covered by a layer of loam two to five feet thick, which is sufficiently different from the underlying drift to attract attention. It varies from a moderately stiff clay on the one hand, to a rather sandy loam on the other. It is generally heavier than its substratum, though influenced to some extent by it. Where it overlies stratified drift, it is on the whole less clayey than where it overlies till. It is sometimes altogether free from stony material, though this is not the rule. The absence of stony material is more likely to be the fact where the loam is thick than where it is thin, and where it overlies stratified drift, than where it overlies unstratified. The stony content of the loam may be either coarse or fine. If it contain bowlders, as it sometimes does, they are in all cases, so far as seen, of a somewhat distant origin. Among the drift bowlders of the region diabase predominates, and every bowlder seen in the loam was of this type. The bowlders of the loam do not differ in shape from the bowlders of the same sort in the body of the drift. On the other hand, where the loam contains small stones they are in almost all cases of chert such as might have come from the local rock, especially the Lower Magnesian limestone; but in small bits it is not always possible to distinguish Lower Magnesian limestone chert from chert of other formations. The cherts are almost uniformly sharply angular. The stony matter both of the bowlder type and of the smaller pieces is more likely to occur at or near the base of the loam, than at or near its top. Occasionally there is an aggregation of small stones at the junction of the till and loam. So well developed and so persistent is this loam that the surface of whole fields and even farms is without a trace of bowlders, even where the till is notably bowldery.

There seems to be no special rule concerning the topographic distribution of the loam, further than that it is generally most

apparent on approximately level surfaces, and that it is least likely to be present on steep slopes. In general it does not appear to be stratified, though where it is thick it is occasionally marked more or less distinctly, with dark and light bands in an essentially horizontal position. This variation in color is probably the result of chemical changes since its deposition, brought about by the concentration of coloring matter along definite horizontal lines. The concentration along these definite plains probably means some variation in texture along these plains, and this probably points to stratification.

As seen in section, the contact of the loam above with the till below is usually irregular, but often sharply marked. Both the regularity and the distinctness of the contact are more striking between the loam and stratified drift than between the loam and till.

Where the loam overlying till attains a thickness of as much as four or five feet the lower portion very commonly approaches loess in character. Where the loam is thin, say two or three feet thick only, it does not resemble loess, though it is not unlike the uppermost two or three feet of clay-loam which overlies loess in regions where the latter has its more clayey and less normal development.

The suggestion of connection between the loam and loess was given added force by finding loess at the two points mentioned, in just such situations and relations as that in which the loam commonly occurs.

Loess at Devils Lake.—East of the south end of Devils Lake fresh railway cuts reveal the presence of loess on the terminal moraine of the Wisconsin epoch. The crest of the moraine along the line of the railway at this point is, according to the topographic map, between 60 and 80 feet above the lake. The loess may be seen on both the inner and outer slopes of the moraine, but does not cover its summit, failing to reach it on either side by about ten feet.

While some of the loess here is thoroughly typical, it locally grades, either horizontally or vertically, into clay which is very

unlike loess. It is sometimes capped by several feet of heavy clay, which is clearly not the product of loam-weathering. Calcareous concretions occur but rarely, as also those of iron oxide. Shells were not seen. The loess, and especially the associated and genetically equivalent clay, contains an occasional stone of considerable size. The loess, and the clay which goes with it, have a maximum thickness of not less than fifteen feet.

There seems to be adequate reason for believing that the loess on the outside of the moraine (toward the lake), was accumulated in the expanded lake which occupied the site of the present lake and its surroundings at the time of ice occupancy. There is independent evidence that the lake stood at least sixty-five feet above its present level. This evidence is found in the presence of what appear to be berg-floated bowlders, up to this height about the borders of the depression (then a bay) at the southwest corner of the lake.

The loess on the inner slope of the moraine doubtless settled out of water which stood there after the ice had withdrawn a short distance to the east.

Loess at Ablemans.—Ablemans is about eight miles west of the moraine of the Wisconsin epoch, and in an area not overspread by the ice of any earlier epoch. Here at the extensive sandstone quarries, there is a fine exposure of loess not less than twenty feet in thickness. It occurs at a rather low altitude, and in such topographic relations as to bring it into unmistakable connection with the broad lacustrine (now terrace) flat which occupies the valley of the Baraboo, from Baraboo to Ablemans. The exposure is in a ravine, tributary to the Baraboo, and but a few rods from it. The lacustrine flat with which this loess is to be correlated is generally made up, superficially at least, of laminated calcareous clay, very unlike loess. It is to be especially noted that the loess at Ablemans does not occur next the moraine, but eight miles away in a small tributary ravine, the head of which did not receive glacial drainage, and that much finer deposits (clay) occur in the main valley between the loess and the moraine where the water was discharged from the ice

to the lake. The loess is here rich in calcareous concretions, and in gastropod shells of the types which abound in the loess. It also posesses the normal loess texture and structure. Indeed much of it is not wanting in a single distinctive loess characteristic. Bones of small mammals, as yet unidentified, were found at this point, at least ten feet below the top of the loess, and in such relations as to make it certain that the loess had not been disturbed or the bones introduced since the deposition of the formation. The loess here lies against a steep slope of sandstone and quartzite, and occasionally contains fragments of each.

A few rods away, at the same, or approximately the same level, an exposure in an isolated remnant of the terrace shows it to be made up of sand interbedded with loam which approaches loess in texture. The sand and loam are distinctly stratified and the stratification appears to be the work of water. The sand and loam at this exposure do not lie against a rock slope and no stones or pebbles were found in it.

The occurrence of loess at Ablemans is of special interest because it connects itself with the deposits of the lake which formerly occupied the valley of the Baraboo above the city of the same name. The lake was called into existence because the ice blocked the eastward drainage of the valley. It was maintained for a short time after the ice retired by the moraine dam which it left just above the City of Baraboo, Its position in a ravine through which glacial drainage did not flow, is also of significance.

The loess at Devil's Lake and at Ablemans, like that in the vicinity of Green Lake, was certainly deposited by water, and by water associated with the ice of the last glacial epoch. With the loess of Ablemans is to be correlated the clay in the valley of the Baraboo exposed at various points above the city, and the loams and clays, some of which are very loess-like, in the valleys of Seeley's and Narrow's creeks south of the Baraboo. The loam at Logansville in one of these valleys was seen many years ago to contain shells, and to be in other ways, somewhat loess-

like. At this point (Logansville) it is distinctly stratified, in places at least, and constitutes, or at any rate covers, the valley flat.

Loess-like loam about Baraboo.—In addition to the distinct development of loess at Devil's Lake, the surface of the drift about Baraboo is often marked by loam no less distinct than that about Green Lake. The surface loam does not seem to be restricted to the surface of the drift, but affects the extra-glacial surface as well. Even the high quartzite ridges seem to have a capping of it, though it cannot be affirmed that the loam (or clay) on these ridges is the equivalent of that over the drift.

The "east bluff" (the quartzite bluff east of the lake), 1560 feet above the sea level, and 800 feet above the valley of the Wisconsin five miles to the south, has a goodly development of clay-loam (five or six feet) upon it. This is exposed in but few places, but the sturdy character of the forest shows that there must be some soil other than that which could have arisen from the decomposition of the quartzite. At the spot where the problematical gravel heretofore described occurs[1] the gravel overlying the quartzite is covered by five to six feet of nearly stoneless clay loam. Its aspect is such as to suggest its genetic connection with the loess. This loam, or something very like it, whatever its origin, is widespread. Whatever is true of the extra-glacial surface loams, that which overlies the drift about Baraboo seems to belong with that which overlies the drift at Green Lake, and which so frequently grades toward normal loess and sometimes assumes the character typical of that formation. I now believe it to be the equivalent of the stoneless, or well nigh stoneless, mantle of clay which occurs at some points about Madison, and which I was formerly inclined to regard as wind-blown dust accumulated on the ice and deposited in the final melting.[2] In the adequacy of this suggestion I

[1] JOUR. OF GEOL., Vol. III, p. 655.

[2] Proc. Am. Ass. for Adv. of Sci. 1893, p. 180. See also Ann. Report of the State Geologist of N. J., 1893, pp. 211–24.

have less confidence than formerly. The phenomenon to be explained is widespread and may involve a much bolder hypothesis.

Loess-like loam near Camp Douglas, Wis.—In the vicinity of Camp Douglas, Wis., there is a considerable development of loess-like loam which is probably genetically connected with loess, though lithologically not identical with the normal phase of that formation. Nevertheless it frequently approaches loess very closely in physical character.

Like Ablemans, Camp Douglas is outside the glaciated area. The station itself is about twenty miles west of the Wisconsin River, on a base-level plain of somewhat extensive development. About the Camp the general plain is marked by occasional notable elevations of sandstone rising up about 200 feet above the flat. To the west there is a dissected plain at a corresponding elevation. Above this plain, which represents a base-plain older than that already referred to, rise other elevations something like 200 feet higher. These are remnants of a base-plain developed during a still earlier cycle of erosion. The dissected plain which stands 200 feet or so above the railway at Camp Douglas is of sandstone, but it is mantled by a clay-loam, to which the sandstone could hardly have given rise. It is rarely exposed, but about four miles northwest of Camp Douglas a section may be seen which shows that, in its general features, it is very similar to loess; that, indeed, it is indistinguishable from some of the less normal phases of that formation. The exposure is at the head of a ravine cut into the upper plain referred to, and from its position and relations there can be no doubt of its continuity and genetic unity with the clay-loam mantle which overspreads the plain.

It is possible that the lowest plain about Camp Douglas was flooded by glacial water during the Wisconsin epoch of the glacial period. It is tolerably certain that the higher plain was not so covered. This loess-like loam is therefore believed to be connected, not with the Wisconsin formation, but with one of

the earlier epochs, though which one, it is, in the light of present knowledge, impossible to say.

Whether loess or anything genetically equivalent to it extends over the elevations which rise above the dissected plain has not yet been determined. The remnants of this earlier and higher plain, so far as visited, were limited in extent, and any loam which might once have covered them would be likely to have disappeared. It is to be borne in mind, however, that these elevations are lower than the Baraboo quartzite ranges, over which clay loam has been deposited in recent time.

There can be little doubt that loam, sometimes clayey (especially over limestone), and sometimes sandy (especially over sandstone), but in all probability genetically connected with the loess, is widespread in the driftless area.

ROLLIN D. SALISBURY.

GEOLOGY OF CHIAPAS, TABASCO AND THE PENINSULA OF YUCATAN.[1]

STRATIGRAPHY.

If one observes the general features of the distribution of the geological formations which constitute the states of Southeastern Mexico he soon finds that in the states of Chiapas and Tabasco there are various distinct geological zones; a very ancient one in the south of Chiapas formed of plutonic rocks and Palæozoic formations; another, more modern, in the middle and northern regions made up of Mesozoic and Tertiary formations. At the foot of each of the above mentioned zones Quaternary deposits are found, forming great plains slightly elevated above sea level. In the Peninsula of Yucatan there is not such a variety of geological formations. Nearly all that extensive region presents a uniform character, which shows that there have not been there so many geological disturbances as in the mountainous regions of Chiapas, and that these deposits were formed under different conditions. In treating of the orography I will speak more in detail of these differences. Yucatan is a part of the earth which has not participated in the dislocations and depressions that the sedimentary deposits, both Palæozoic as well as Cretaceous and Tertiary, of Chiapas have undergone, resulting in the development of mountain chains in that state. The strata are almost horizontal or a little inclined in Yucatan,

[1] Boletín del Instituto Geológico de México, Num. 3, La Geografia Fisica y la Geologia de la Peninsula de Yucatan, Mexico. 1896. Roy. 4°, 57 pp., 2 pl. of sections and 3 folded maps.

The work from which the following translation is taken is divided into five parts, viz., geology, orography, hydrography, climatology and distribution of the floral zones, and productions. Part I, geology, seems to us deserving of a wider circle of readers than it is liable to obtain in its original form, and hence we have prepared this translation. The accompanying photo-engravings are sketched from Sapper's geological maps, and will serve to indicate the general distribution of the different formations as understood by that authority.

while on the contrary those in Chiapas are generally much inclined and fractured.

A. SEDIMENTARY FORMATIONS.

1. *Azoic formations.*—In addition to some very limited bands of gneiss, mica-slate, and phyllites surrounded with granite, which I observed in 1893 in the Sierra Madre, in 1894 I came

across in the first northern range of the same Sierra, near the plantations of "Piedad" and "San Vicente," another band of crystallines trending N. 7° W. and dipping 5° to the N. E. Among bowlders washed down by the Aguacate River one can see gneiss, mica-slate, and phyllites, which indicate the presence of these formations in these regions and in the interior of the Sierra Madre.

On account of the total absence of means of communication in the Sierra mentioned, entrance to the interior, now practically unknown, is almost impossible; hence on the geological map I have not been able to indicate the occurrence of the Azoic formations except in a very general way.

2. *Strata of Santa Rosa.*—As I said in a preliminary report in 1893, I have adopted this term of the French geologists, A.

Dollfus and E. de Montserrat, to indicate a system of red arenaceous and slaty conglomerates which is beneath the Carboniferous limestones. I showed that the upper strata of this system in the neighboring Republic of Guatemala contain Carboniferous fossils, and although it is impossible to determine with exactness the age of the lower beds, probably they are Carboniferous or Devonian. The extent of the Santa Rosa beds is very considerable, since near Porvenir, in San Francisco Motozintla, there are important mountain chains formed almost exclusively of these beds.

These beds, like the Carboniferous limestones, are found only in the southeastern part of Chiapas. I was unable to ascertain exactly how far west they extend, but I think that they terminate at their contact with the granite rocks which form the nucleus of the Sierra Madre.

3. *Carboniferous limestone.*—The limestones and dolomites of the Carboniferous terranes have a moderate extension in the state of Chiapas, as is shown on the geological map. Their age is roughly ascertained by various fossils which I have found in the vicinity of La Nueva, Las Tres Cruces, and Palo Amarillo, which have not yet been determined (specifically).

I have also found Carboniferous fossils, as brachiopods, corals, and crinoids, near San Vicente, in the department of Comitan, in calcareous rocks, cemented together with silicon, probably in Tertiary times. At nearly all the points which I know the Carboniferous limestones lie conformably upon the Santa Rosa beds. In the vicinity of Chicomucelo and Palo Amarillo beds of limestone were seen intercalated between the slates and flagstones of the above-mentioned beds. In the preliminary report of 1894 and in the "Grundzuge der physicalischen Geographie von Guatemala" (Gotha, 1894), I have given the list of the Carboniferous fossils which up to the present date have been found in the Republic of Guatemala.

4. *Strata of Todos Santos.*—A system of sandy and slaty conglomerates of a red or reddish color, which I have termed for reasons before given the "strata of Todos Santos," are found

along the northern base of the Sierra Madre. The beds are a little inclined to the north in many places where I was able to ascertain the dip. They do not lie conformably over the Carboniferous limestones, and apparently their deposition occurred after the primary formation of the Sierra Madre, along the shores and bottom of a sea, later than the Carboniferous but before the Cretaceous, and that they have undergone few dislocations or alterations.

I cannot give any exact data on the relative age of these beds because I have found no fossils in them. Perhaps they are deposits of the Triassic period, the latter having been found in the Republics of Honduras [1] and Nicaragua.[2]

The formations 1 to 4 occur only in the southern part of Chiapas. The northern parts of the same state are made up of more recent sedimentary rocks, of the Cretaceous and Tertiary.

5. *Cretaceous limestone.*—In the greater part of the northern region of Chiapas are limestones and dolomites, both of the Cretaceous period. I have found *Rudistes*, *Radiolites sp.*, and *Spherulites sp.* between San Cristobal, Las Casas, and Teopisca, between Teopisca and San Lazaro, between San Bartolomé de los Llanos and San José de La Canoa, between Santa Isabel and Campana (Department of Comitán, near Comitan), between El Calvairo and Chiapa, between San Vicente and Soyaló, where I also met with some Nerineas, near to San Cristobal, Las Casas, and between Yochiu and Tenejapa. All these points are situated in the southern part of the Cretaceous belt.

In the northern portions of the same zone I could not find any traces of Rudistes, but I found remains of fossil corals in various places, as in La Puncta, the Catate and Salvador rivers, between Sabanilla and Tila, and between Tila and Tumbalá.

These organic remains have not been examined with sufficient care as yet to enable one to say whether the limestones containing the rudistes and those containing the corals belong

[1] Dr. R. Fritzgartner, Kaleidoscopic views of Honduras, in Honduras Mining Journal. 1891. Num. 6–8. Tegucigalpa.

[2] Dr. Bruno Micrisch, Eine Reise quer durch Nicaragua, in Petermann's Mitteilungen. Gotha, 1895. Pp. 57, et seq.

to different horizons of the Upper Cretaceous, or whether they are contemporaneous formations of different appearance.

I found a fossil fish in a very fine-grained limestone which resembles the lithographic stone of Solenhofen. The ancient Indians used this stone in the construction of Palenque.

In the strata which occur in the eastern part of Chiapas I have not obtained fossils either along the road from Tenosique to Real, or on the banks of the Usumacinta and Lacantún. Yet I think that they are Cretaceous because in the eastern continuation of the few sierras of Chiniquijá, I have found in La Libertad, department of the Petén, a few badly preserved fossils which Geheimerat von Zittel, in Munich has examined and determined to be Cretaceous.

6. *Cretaceous Marls and Clays.*—Near Tuxtla Gutiérrez and Chiapa there are some deposits of marls and clays which contain fossils, as yet not well studied, of the genera *Heliopora*, *Leptophyllia*, *Goniastræa*, *Stylina*, *Cryptocœnia* and *Turritella*. They are of an Upper Cretaceous horizon and more modern than the Cretaceous limestones on which they lie. I do not remember meeting with these beds in any other part of the state. The strata of this formation are a little inclined, or sometimes horizontal, as in the valley of Tuxtla and Chiapa.

7. *Tertiary.*—The Tertiary is found in many parts of the northern and central regions of Chiapa and in the southern part of Tabasco. In Tabasco the Tertiary is for the most part covered over with thin Quaternary strata.

As I have said in the preliminary report of 1893, the majority of the Tertiary is composed of marls and clays, sands and conglomerates while the limestones are of less importance.

I repeat that I found in 1893 a species of *Pecten* near Zacualpa, *Ostreas*, *Nummulites*, *Clypeaster*, and different gastropods, lamellibranchs and corals near Sacramento, the Relcario, Testaquim and Istapa, belonging, as far as have been examined, some to the Upper Miocene and some to a lower horizon. In 1889 I found near San José, department of the Comitán, remains of plants and foraminifera which Mr. C. Schwager in Munich deter-

mined as Tertiary. In 1891 I found in the alluvium of the Chixoy River Tertiary species of *Ostrea* and *Cerithium*.

In 1894 I found Tertiary fossils near Moyos, Sabanilla, Tila and Tumbalá; *Ostraæ* in Tenosique, near Chinajá, in San Antonio, department of La Libertad, Chiapas; near Tenejapa and at other points. Other Tertiary fossils (Lamellibranchs) were found by D. Joaquín Zetina on the banks of the Lacanjá River, the Aguilar and other streams, and one *Ostrea* by D. Jose Tamborrel in the southern part of Tenosique.

I found in Real, department of Chilón, and in San Antonio, department of La Libertad, Chiapas, fossil plants in Tertiary terraines; but as they were not in place, I could not determine their age.

The Tertiaries are generally very much inclined; in the neighborhood of Istapa, of San Antonio, of Tenejapá and Tumbala, the strata are horizontal or of very gentle dip; they are more modern than the andesitic eruptions because they enclose pebbles of the latter, as in Burrero, district of Istapa; and in some cases the horizontal rocks lie directly above the andesite, as near to Tenejapa.

In the peninsula of Yucatan Tertiary beds predominate; and it seems that from the south to the north the successive strata become more and more recent until the Post Pliocene and Quaternary of the north coast is reached. I think that the nearly horizontal or little inclined Tertiary beds of Yucatan which I have observed, have a general, gentle slope toward the north, and that a great part of the more recent Post Pliocene beds were submerged under the sea in comparatively recent times as Heilprin concludes was the case with the "Banco de Yucatan," and quite probably the submerging took place very slowly, just as now, according to my own observations, the Atlantic coast of Guatemala is slowly sinking.

The southern parts of Yucatan show calcareous formations often containing much silicous matter. Among the limy layers, too, are occasional beds of marl and others of gypsum (alabaster). In the mountain chain of Ixconconcal, near Icaiché, I

found a number of fossils which could be used for determining the age of these deposits. The gypsiferous layers have not been seen to the north of the vicinity of Haltum.

Certainly these southern deposits belong to a lower horizon than the northern deposits which were studied by Professor Angelo Heilprin. This noted geologist has distinguished the following horizons:

(*a*) Limestones, gray or white in color, which can well be studied in the cave of Calcehtok, the entrance of which is 200 English feet above sea level, Fossils are rare and the following only were found: *Pecten nucleus*, *Pecten* sp., *Marginella* (sp. cf. *labiata*), *Potamides*, or *Cerithides*, *Oliva*, *Venus cancellata*. Mr. Heilprin says that the age of this limestone is Miocene or Pliocene, and not Oligocene as has been held by Alexander Agassiz.[1]

(*b*) Limestones, red or reddish in color, lying above semi-crystalline marble or yellow limestones, very fine-grained, resembling the lithographic limestone of Solenhofen. Breccias of limestone occur at the foot of the hills. In the red limestone a *Helix* was found between Ticuli and Santa Elena, at an altitude of 300 feet above sea level, and another fossil which seemed to be a *Macroceramus*, in the cave of Calcehtok. Both these fossils are terrestrial, but it could not be said with certainty whether all the limestone is of terrestrial origin. The above limestones occur in the hilly parts of Yucatan. I notice that Mr. Heilprin does not mention the flint masses which are found in the same regions and which are used in the vicinity of Ticul for the manufacture of mill stones.

(*c*) The Pliocene limestone which predominates in the low regions of the north of Yucatán and which was examined by Mr. Heilprin, especially in Mérida, and between Mérida and Calkini, Mérida and Ticul, Mérida and Tunkás, and between Tekanto and Silam.

Professor Heilprin has found in it the following fossils:

Pecten nucleus,	Tekanto, Mérida, between Mérida and Ticul.
Pecten n. sp.,	"

[1] Three Cruises of the Blake, Vol. I, p. 69.

Anomia simplex, (?)	
A. Ruffini ?	
Plicatula filamentosa,	Tekanto.
Lucina reticulata,	"
Arca Adamsi	"
Venus mercenaria,	"
Venus cancellata,	Tekanto, Mérida, between Mérida and Ticul.
Marginella apicina,	"
* *Turritella peratenuata*,	"
* *Turritella apicalis*,	"
Bulla striata,	"
* *Amusium Mortoni*,	Izamal, Mérida.
Cardium isocardia,	Mérida.
Venus Listeri,	"
Pecten sp. ?	Between Mérida and Ticul.
Pinna sp. ?	" " "
Lucina Jamaicensis,	" " "
Lucina edentula,	" " "
Cardium Magnum ?	" " "
Cardium muricatum,	Mérida.
Murex Salleanus,	Between Mérida and Ticul.
* *Ostrea meridionalis*,	Mérida.
Arca Deshayesii,	"
* *Arca* sp.,	"
Arca rombea,	"
* *Pectunculus* sp.,	"
Lucina tigrina	"
* *Lucina disciformis*,	"
Lucina Pennsylvanica,	"
Cardium serratum.	
Chama arcinella,	"
Venus Mortoni,	"
Artemis discus,	"
Macoma contracta,	"
Tellina sp.,	"
* *Fulgur rapum*,	"
Dolium perdix,	"
Oliva literata,	"
Cypræa sp.,	"
Pyrula reticularis,	"
Siliquaria sp.	"

* Not living in neighboring seas.

All these fossils are of the Pliocene; the formation is equivalent to that of Florida. Corals are rare and have not contributed to any great degree to the formation of the rocks. The fossils which I found in Mérida have not as yet been determined.

8. Post-Pliocene or Quaternary limestone, only on the northern coast and in the isolated patches in the interior of the peninsular; the remainder of the formation in the interior has been destroyed by erosion. It is characterized by *Venus cancellata* and according to Heilprin, continues northward under the sea.

B. ERUPTIVE FORMATIONS.

9. *Granite.*—Granite forms the greater part of the Sierra Madre of Chiapas; one reddish variety occurs in the northern part of that mountain chain. This granite seems to be of a later age than the Carboniferous, because the mountain chains composed of the limestone of that terrane and of the Santa Rosa beds cease abruptly upon contact with the plutonic rocks of the Sierra Madre. I have been unable to study the conditions at these points on account of the total absence of roads.

10. *Diorite.*—Diorite occurs in the northwest part of Chiapas and forms by itself a few mountain chains; it appears to be of Tertiary Age.

11. *Serpentine.*—In the region of San Francisco Motozintla various dikes of serpentine of a limited area occur between Malpaso and San Isidoro and in the vicinity of Chimalapa.

12. *Andesite.*—Andesite eruptions have been found only in the State of Chiapas; in the northwest, andesitic hypersthene is found forming a mountain chain of considerable altitude (more than 2000 [meters?]), and in the central part of the state hornblendic andesite occurs forming the chains to the north and southwest of San Cristobal, Las Casas and the picturesque chains of Mispilla and San Bartolomé de los Llanos, besides many dikes of minor importance. These andesites made their eruptions successively during the Tertiary epoch and before the formation of the Neo-tertiaries of Burrero near Istapa and Tene-

japa, but probably after the dislocations of the beds of the Upper Miocene of Sacramento. In the Sierra Madre there were other great eruptions. I have been unable as yet to mark out the westward limit.

VOLCANOES.

The only volcano known in the state of Chiapas is Tacaná (3990 meters), through the apex of which passes the dividing line between the Republics of Mexico and Guatemala. Its latest eruption took place in 1855.

CARLOS SAPPER.

[Translated by C. Joaquina Maury and G. D. Harris.]

STUDIES FOR STUDENTS.

STRATIFIED DRIFT.

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Its abundance.—The notion is widespread that the drift deposits of the glacial period are unstratified. Lack of stratification, indeed, is the characteristic which, above all others, is popularly supposed to be the special mark of the formations to which the ice gave rise.

While it is true that glacier ice does not distinctly stratify the deposits which it makes, it is still true that a very large part of the drift for which the ice of the glacial period was directly or

indirectly responsible is stratified. That this should be so is not strange when it is remembered that most of the ice was ultimately converted into running water, just as the glaciers of today are. The relatively small portion which disappeared by evaporation was probably more than counterbalanced, at least near the margin of the ice, by the rain which fell upon it. It cannot be considered an exaggeration, therefore, to say that the total amount of water which operated upon the drift, first and last, was hardly less than the total amount of the ice itself. The drift deposited by the marginal part of the ice was affected during its deposition, not only by the water which arose from the melting of the ice which did the depositing, but by much water which arose from the melting of the ice far back from the margin. The general mobility of the water, as contrasted with ice, allowed it to concentrate its activities along those lines which favored its motion, so that different portions of the drift were not affected equally by the water of the melting ice.

All in all it will be seen that the water must have been a very important factor in the deposition of the drift, especially near the margin of the ice. But the ice-sheet had a marginal belt throughout its whole history, and water must have been active and effective along this belt, not only during the decadence of the ice-sheet, but during its growth as well. It is further to be noted that any region of drift stood good chance of being operated upon by the water after the ice had departed from it, so that in regions over which topography directed drainage after the withdrawal of the ice, the water had the last chance at the drift, and modified it in such a way and to such an extent as circumstances permitted.

Its origin.—There are various ways in which stratified drift may arise in connection with glacier deposits. It may come into existence by the operation of water alone; or by the coöperation of ice and water. Where water alone was immediately responsible for the deposition of stratified drift, the water concerned may have owed its origin to the melting ice, or it may have existed independently of the ice in the form of lakes or

seas. When the source of the water was the melting ice, the water may have been running, when it was actively concerned in the deposition of stratified drift, or it may have been standing (glacial lakes and ponds) when it was passively concerned. When ice coöperated with water in the development of stratified drift the ice was generally a passive partner.

GLACIAL DRAINAGE.

The body of an ice-sheet during any glacial period is probably melting more or less at some horizons all the time and at all horizons some of the time. Most of the water which is produced at the surface during the summer sinks beneath it. Some of it may congeal before it sinks far, but much of it reaches the bottom of the ice without refreezing. It is probable that melting is much more nearly continuous in the body of a moving ice-sheet than at its surface, and that some of the water thus produced sinks to the bottom of the ice without refreezing. At the base of the ice, so long as it is in movement, there is doubtless more or less melting, due both to friction and to the heat received by conduction from the earth below. Thus in the ice and under the ice there must have been more or less water in motion throughout essentially all the history of an ice-sheet.

If it be safe to base conclusions on the phenomena of existing glaciers, it may be assumed that the waters beneath the ice, and to a less extent the waters in the ice, organized themselves to a greater or less degree into streams. For longer or shorter distances these streams flowed in the ice or beneath it. Ultimately they escaped from its edge. The subglacial streams doubtless flowed, in part, in the valleys which affected the land surface beneath the ice, but they were probably not all in such positions.

The courses of well-defined subglacial streams were tunnels. The bases of the tunnels were of rock or drift, while the sides and tops were of ice. It will be seen, therefore, that their courses need not have corresponded with the courses of the valleys beneath the ice. They may sometimes have followed lines

more or less independent of topography, much as water may be forced over elevations in closed tubes. It is not to be inferred, however, that the subglacial streams were altogether independent of the sub-ice topography. The tunnels in which the water ran probably had too many leaks to allow the water to be forced up over great elevations. This, at least, must have been the case where the ice was thin or affected by crevasses. Under such circumstances the topography of the land surface must have been the controlling element in determining the course of the subglacial drainage.

When the streams issued from beneath the ice the conditions of flow were more or less radically changed, and from their point of issue they followed the usual laws governing river flow. If the streams entered static water as they issued from the ice, and this was true where the ice edge reached the sea or a lake, the static water modified the results which the flowing waters would otherwise have produced.

STAGES IN THE HISTORY OF AN ICE-SHEET.

The history of an ice-sheet which no longer exists involves at least two distinct stages. These are (1) the period of growth, and (2) the period of decadence. If the latter does not begin as soon as the former is complete, an intervening stage, representing the period of maximum ice extension, must be recognized. In the case of the ice-sheets of the glacial period, each of these stages was probably more or less complex. The general period of growth of each ice-sheet is believed to have been marked by temporary, but by more or less extensive intervals of decadence, while during the general period of decadence, it is probable that the ice was subject to temporary, but to more or less extensive intervals of recrudescence. For the sake of simplicity, the effects of these oscillations of the edge of the ice will be neglected at the outset, and the work of the water accompanying the two or three principal stages of an ice-sheet's history will be studied

as if interruptions in the advance and in the retreat, respectively, had not occurred.

As they now exist, the deposits of stratified drift made at the edge of the ice or beyond it during the period of its maximum extension present the simplest and at the same time most sharply defined phenomena, and are therefore considered first.

DEPOSITS MADE BY EXTRAGLACIAL WATERS DURING THE MAXIMUM EXTENSION OF THE ICE.

The deposits made by the water at the time of the maximum extension of the ice and during its final retreat, were never disturbed by subsequent glacier action. So far as not destroyed by subsequent erosion, they still retain the form and structure which they had at the outset. Such drift deposits, because they lie at the surface, and because they are more or less distinct topographically as well as structurally, are better known than the stratified drift of other stages of an ice-sheet's history.

Of stratified drift made during the maximum extension of the ice, and during its final retreat, there are several types. Some of them have been adequately described and defined in the literature of glacial geology, and would need no more than passing reference in this connection, were it not that, under certain conditions, they lose their distinctive characteristics, without being altogether destroyed. Their recognition then becomes a matter of difficulty, and their real relations are likely to be misunderstood, when the phenomena are in reality rather simple.

A. At the edge of ice, on land.—If the subglacial streams flowed under "head," the pressure was relieved when they escaped from the ice. With this relief, there was diminution of velocity. With the diminution of velocity, deposition of load would be likely to take place. Since these changes would be likely to occur at the immediate edge of the ice, one class of stratified drift deposits would be made in this position, in immediate contact with the edge of the ice, and their form would be influenced by it. At the stationary margin of an ice-sheet, there-

fore, at the time of its maximum advance, ice and water must have coöperated to bring into existence considerable quantities of stratified drift.

The edge of the ice was probably ragged, as the ends of glaciers are today, and as the waters issued from beneath it, they must frequently have left considerable quantities of such débris as they were carrying, against its irregular margin, and in its reëntrant angles and marginal crevasses. When the ice against which this débris was first lodged melted, the marginal accumulations of gravel and sand often assumed the form of *kames*, a type of stratified drift which is well known.[1] A typical kame is a hill, hillock, or less commonly a short ridge of stratified drift; but several or many are often associated, giving rise to groups and areas of kames. Kames are often associated with terminal moraines, a relation which emphasizes the fact of their marginal origin.

So far as the superficial streams which flowed to the edge of the ice carried débris, this was subject to deposition as the streams descended from the ice. Such drift would tend to increase the body of marginal stratified drift from subglacial sources.

Marginal accumulations of stratified drift, made by the coöperation of running water and ice, must have had their most extensive development, other things being equal, where the margin of the ice was longest in one position, and where the streams were heavily loaded. The deposits made by water at the edge of the ice differ from those of the next class — made beyond the edge of the ice — in that they were influenced in their disposition and present topography, by the presence of ice.

[1] Until recently kames have not been discriminated from eskers, and in the older literature the two are confused. Kames, as distinct from eskers, are defined and discussed in the following places, though the list is incomplete:

CHAMBERLIN, 3d Ann. Rep. U. S. Geol. Surv., p. 300; Am. Jour. Sci., Vol. XXVII, p. 378; Compte-Rendu, 5th Session International Congress of Geologists, p. 187; JOURNAL OF GEOLOGY, Vol. I, p. 255; JOURNAL OF GEOLOGY, Vol. II, p. 531. GEIKIE, "Great Ice Age," 3d Edition, chap. xv. SALISBURY, Report of the State Geologist of New Jersey for 1891, pp. 89–95; Ibid., 1892, pp. 41, 79.

B. Beyond the edge of the ice, on land.—As the waters escaping from the ice flowed farther, deposits of stratified drift were made quite beyond the edge of the ice. The forms assumed by such deposits are various, and depended on various conditions. Where the waters issuing from the edge of the ice found themselves concentrated in valleys, and where they possessed sufficient load, and not too great velocity, they aggraded the valleys through which they flowed, developing fluvial plains of gravel and sand, which often extended far beyond the ice. Such fluvial plains of gravel and sand constitute the *valley trains*[1] which extend beyond the unstratified glacial drift in many of the valleys of the United States. They are found especially in the valleys leading out from the stouter terminal moraines of later glacial age. From these moraines, the more extensive valley trains take their origin, thus emphasizing the fact that they are deposits made by water beyond a stationary ice margin. Valley trains have all the characteristics of alluvial plains built by rapid waters carrying heavy loads of detritus. Now and then their surfaces present slight variations from planeness, but they are minor. Like all plains of similar origin they decline gradually, and with diminishing gradient, down stream. They are of coarser material near their sources, and of finer below. Such stratified drift, which constitutes a distinct topographic, as well as genetic type, is well known, and further description or discussion is unnecessary.

Where the subglacial streams did not course through subglacial valleys, they did not always find valleys at hand upon their issuance from the ice. Under such circumstances, each heavily loaded stream coming out from beneath the ice must have tended to develop a plain of stratified material near its point of issue—a sort of alluvial fan. Where several such streams came out from beneath the ice near each other for a considerable period of time, their several plains, or fans, were

[1] For fuller definition and illustration of valley trains see CHAMBERLIN, 3d Ann. Report U. S. Geol. Surv., p. 302; JOURNAL OF GEOLOGY, Vol. I, p. 534. SALISBURY, Report of the State Geologist of New Jersey, 1892, pp. 102–107.

likely to become continuous by lateral growth. Such border plains of stratified drift differ from valley trains particularly (1) in being much less elongate in the direction of the drainage; (2) in being much more elongate parallel to the margin of the ice; and (3) in not being confined to valleys. Such plains stood an especially good chance of development where the edge of the ice remained constant for a considerable period of time, for it was under such conditions that the issuing waters had opportunity to do much work.

Thus arose the type of stratified drift variously known as *overwash plains*, *morainic plains*, and *morainic aprons*. These overwash plains are sometimes found with a width of several miles. Like the valley trains, they are topographically and genetically distinct, and their relations are well known. They have been abundantly described in the literature of glacial geology, and it is, therefore, not needful that more be said concerning them at this point.[1]

Overwash plains may sometimes depart from planeness by taking on some measure of undulation, of the sag and swell (kame) type, especially near their iceward edges. The same is often true of the heads of valley trains. The heads of valley trains and the inner edges of overwash plains, it is to be noted, occupy the general position in which kames are likely to be formed, and the undulations which often affect these parts of the trains and plains, respectively, are probably to be attributed to the influence of the ice itself. Valley trains and overwash plains, therefore, at their upper ends and edges respectively, may take on some of the features of kames. Indeed, either may head in a kame area.[2]

Occasionally a morainic apron, or stratified drift in the general position of a moraine apron, is affected by numerous sags without corresponding elevations. This topographic type has

[1] This type is described in the following places, among many others:

CHAMBERLIN, 3d Ann. Report U. S. Geol. Surv., p. 303; JOURNAL OF GEOLOGY, Vol. II, p. 533. SALISBURY, Ann. Report of the State Geologist of New Jersey, 1892. p. 97.

[2] SALISBURY, Ann. Report of State Geologist of New Jersey, 1892, p. 94.

received the name of *pitted plain*. The sags, in many cases at least, appear to be intimately connected with the ice edge, and so to be marginal phenomena.

Not only may morainic plains and valley trains grade into kame areas at their heads, but they may grade into each other. A wide valley train and a narrow overwash plain may closely simulate each other, and in individual cases it is not easy to say whether the deposits are more properly referred to the one or the other of the two classes.[1] This is especially true where an overwash plain is developed in a valley.

At many points near the edge of the ice during its maximum stage of advance, there probably issued small quantities of water not in the form of well-defined streams, bearing small quantities of detritus. These small quantities of water, with their correspondingly small loads, were unable to develop considerable plains of stratified drift, but produced small patches instead. Such patches have received no special designation.

When the waters issuing from the edge of the ice were sluggish, whether they were in valleys or not, the materials which they carried and deposited were fine instead of coarse, giving rise to deposits of silt, or clay, instead of sand or gravel.

In the deposition of stratified drift beyond the edge of the ice, the latter was concerned only in so far as its activity helped to supply the water with the necessary materials.

C. Deposits at and beyond the edge of the ice in standing water.— The waters which issued from the edge of the ice sometimes met a different fate. The ice in its advance often moved up river valleys. When at the time of its maximum extension, it filled the lower part of a valley, leaving the upper part free, drainage through the valley stood good chance of being blocked. Where this happened a marginal valley lake was formed. Whenever the ice spread over a land surface sloping toward it, there was the possibility of the development of a lake basin between the ice on one hand, and the land surface on the other. Marginal lakes and ponds arising in these and other

[1] SALISBURY, Annual Report of the State Geologist of New Jersey, 1891, p. 97.

ways, were probably not rare at the time of the maximum extension of the ice, and more or less drainage from the ice must have found its way into them. Wherever this occurred, stratified deposits of drift were made in the lakes, the materials for which were borne into the standing water by the streams which issued from the ice. *Deltas* must have been formed where well-defined streams entered the lakes, and *subaqueous overwash plains*[1] where deltas became continuous by lateral growth. The accumulation of stratified drift along the ice-ward shores of such lakes must have been rapid, because of the abundant supply of detritus. These materials were probably shifted about more or less by waves and shore currents, and some of them may have been widely distributed. Out from the borders of such lakes, fine silts and clays must have been in process of deposition, at the same time that the coarse materials were being laid down nearer shore.

Deposition must have taken place in a similar way along the shores of the sea wherever the ice reached it. The silt, sand, gravel, etc., carried to the sea by running water was either deposited at once, or worked over and transported greater or less distances by waves and littoral currents. Such deposits still remain beneath the sea, unless changes of level have brought them above the surface.

During the maximum extension of an ice-sheet, therefore, there was chance for the development, at its edge or in advance of it, of the following types of stratified drift: (1) kames and kame belts, at the edge of the ice; (2) fluvial plains or valley trains, in virtual contact with the ice at their heads; (3) border plains or overwash plains, in virtual contact with the ice at their upper edges; (4) ill-defined patches of stratified drift, coarse or fine, near the ice; (5) subaqueous overwash plains and deltas, formed either in the sea or lakes at or near the edge of the ice; (6) lacustrine and marine deposits of other sorts, the materials for which were furnished by the waters arising from the ice.

[1] Annual Report of the State Geologist of New Jersey for 1892, p. 99; *ibid.*, 1893, p. 266.

DEPOSITS MADE BY EXTRAGLACIAL WATERS DURING THE RETREAT OF THE ICE.

During the retreat of any ice-sheet, disregarding oscillations of its edge, its margin withdrew step by step from the position of extreme advance to its center. When the process of dissolution was complete, each portion of the territory once covered by the ice, had at some stage in the dissolution, found itself in a marginal position. At all stages in its retreat the waters issuing from the edge of the ice were working in the manner already outlined in the preceding paragraphs. Two points of difference only need to be especially noted. In the first place the deposits made by waters issuing from the retreating ice, were laid down on territory which the ice had occupied, and their subjacent stratum was often glacial dritt. So far as this was the case, the stratified drift was supermorainic, not extra-morainic. In the second place the edge of the ice in retreat did not give rise to such sharply marked formations as the edge of the ice which was stationary. The processes which had given rise to valley trains, overwash plains, kames, etc., while the ice edge was stationary, were still in operation, but the line or zone of activity (the edge of the ice) was continually retreating, so that the foregoing types, more or less dependent on a stationary edge, were rarely well developed. As the ice withrew, therefore, it allowed to be spread over the surface it had earlier occupied, many incipient valley trains, overwash plains, and kames, and a multitude of ill-defined patches of stratified drift, thick and thin, coarse and fine. Wherever the ice halted in its retreat these various types stood chance of better development.

Such deposits would not cover all the surface discovered by the ice in its retreat, since the issuing waters, thanks to their great mobility, concentrated their activities along those lines which favored their motion. Nevertheless the aggregate area of the deposits made by water outside the ice as it retreated, was great.

It is to be noted that it was not streams alone which were operative as the ice retreated. As its edge withdrew, lakes and

ponds were continually being drained, as their outlets, hitherto choked by the ice, were opened, while others were coming into existence as the depressions in the surface just freed from ice, filled with water. Lacustrine deposits at the edge of the ice during its retreat were in all essential respects identical with those made in similar situations during its maximum extension.

Disregarding oscillations of the ice edge at these stages, the deposits made by extraglacial waters during the maximum extension of an ice-sheet, and during its retreat, were always left at the surface, so far as the work of that ice-sheet was concerned. The stratified drift laid down by extraglacial waters in these stages of the last ice-sheet which affected any region of our continent still remain at the surface in much the condition in which they were deposited, except for the erosion they have since suffered. It is because of their position at the surface that the deposits referable to these stages of the last ice-sheet of any given region have received most attention and are therefore most familiar.

DEPOSITS MADE BY EXTRAGLACIAL WATERS DURING THE ADVANCE OF THE ICE.

During the advance of an ice-sheet, if its edge forged steadily forward, the waters issuing from it, and flowing beyond, were effecting similar results. They were starting valley trains, overwash plains, kames, and small ill-defined patches of stratified drift which the ice did not allow them to complete, before pushing over them, and shoving forward the zone of activity of extraglacial waters. Unlike the deposits made by the waters of the retreating ice, those made by the waters of the advancing ice were laid down on territory which had not been glaciated, or at least not by the ice-sheet concerned in their deposition. If the ice halted in its advance, there was at such time and place opportunity for the better development of extraglacial stratified drift.

Lakes as well as streams were concerned in the making of stratified beds of drift, during the advance of the ice. Mar-

ginal lakes were extinguished by having their basins filled with the advancing ice, which displaced the water. But new ones were formed, on the whole, as rapidly as their predecessors became extinct, so that lacustrine deposits were making at intervals along the margin of the advancing ice.

Deposits made in advance of a growing ice-sheet, by waters issuing from it, were subsequently overridden by the ice, to the limit of its advance, and in the process, suffered destruction, modification, or burial, in whole or in part, so that now they rarely appear at the surface.

DEPOSITS MADE BY SUBGLACIAL STREAMS.

Before their issuance from beneath the ice, subglacial waters were not idle. Their activity was sometimes erosive, and at such times stratified deposits were not made. But where the subglacial streams found themselves overloaded, as seems frequently to have been the case, they made deposits along their lines of flow. Where such waters were not confined to definite channels, their deposits probably took on the form of irregular patches of silt, sand, or gravel; but where depositing streams were confined to definite channels, their deposits were correspondingly concentrated. When subglacial streams were confined to definite channels, the same may have been constant in position, or may have shifted more or less from side to side. Where the latter happened there was a tendency to the development of a belt or strip of stratified drift having a width equal to the extent of the lateral migrations of the under-ice stream. Where the channel of the subglacial stream remained fixed in position, the deposition was more concentrated, and the bed was built up. If the stream held its course for a long period of time, the measure of building may have been considerable. In so far as these channel deposits were made near the edge of the ice, during the time of its maximum extension or retreat they were likely to remain undisturbed during its melting. The aggraded channels then came to stand out as ridges. These ridges of gravel and sand are known as *osars* or *eskers*. It is not to be inferred that

eskers never originated in other ways, but it seems clear that this is one method, and perhaps the principal one, by which they came into existence. Eskers early attracted attention, partly because they are relatively rare, and partly because they are often rather striking topographic features. Their characteristics are well known and will not be recounted here.[1] The essential conditions, therefore, for their formation, so far as they are the product of subglacial drainage, are (1) the confining of the subglacial streams to definite channels, and (2) a sufficient supply of detritus.

Subglacial deposits of stratified drift were sometimes made on unstratified drift (till) already deposited by the ice before the location of the stream, and sometimes on the rock surfaces on which no covering of glacier drift had been spread.

It is to be kept in mind that subglacial drainage was operative during the advance of an ice-sheet, during its maximum extension, and during its retreat, and that during all these stages it was effecting its appropriate results. It will be readily seen, however, that all deposits made by subglacial waters, were subject to modification or destruction or burial, through the agency of the ice, and that those made during the advance of the ice were less likely to escape, than those made during its maximum extension or retreat.

DEPOSITS OF SUPERGLACIAL AND ENGLACIAL STREAMS.

Superglacial and englacial streams might be supposed to make deposits in their channels. It has even been conceived that this

[1] Eskers or osars are described and discussed in the following places, often under the name of kames or serpentine kames: CHAMBERLIN, 3d Ann. Report U. S. Geol. Surv., p. 299; Compte-Rendu, 5th Session of the International Congress of Geologists; JOURNAL OF GEOLOGY, Vol. I, p. 255; *Ibid.*, Vol. II, p. 529. STONE, Proc. Bost. Soc. Nat. Hist., Vol. XX, pp. 430–69. UPHAM, Geol. of N. Hampshire, Vol. III, (under kames); Proc. A. A. A. S., Vol. XXV, p. 216; Report Minn. Geol. Survey, Vol. I, p. 545; Am. Jour. Sci., Vol. CXIV (1877), p. 459, SHALER, Proc. Bost. Soc. Nat. Hist., Vol. XXIII, p. 36; 7th Ann. Report U. S. Geol. Surv., p. 314; 9th Ann. Report U. S. Geol. Surv., p. 549. DAVIS, Proc. Bost. Soc. Nat. Hist., Vol. XXV, p. 477–492. GEIKIE, Great Ice Age, 3d edition, Chap. XIV. HOLST, Am. Nat., Vol. XXII, pp. 590–711. SALISBURY, Ann. Rep. State Geologist of New Jersey, 1892, pp. 41, 79.

was the principal mode of origin of eskers. Against this view, and against the view that superglacial stream deposits are of consequence quantitatively, stand two facts. (1) So far as known the surfaces of ice-sheets are free from drift (apart from wind-blown dust) except for a fraction (and generally a small one) of a mile from their edges; and (2) superglacial streams are in general much too swift to deposit drift, or to allow it to accumulate in their channels. The channels of most superglacial streams in North Greenland, *even near the edge of the ice where surface débris is abundant*, are absolutely free from drift. Judging from the force with which they issue from the ice, englacial streams are likewise much too swift to allow of deposition along their channels, as a general rule.

Such trivial accumulations of drift as may be made in superglacial or englacial channels would ultimately reach the land surface. During the advance of the ice they would be delivered onto the land, as the ice which sustained them moved forward into the zone of melting. They would then be overridden by its further forward motion. During the retreat of the ice, such deposits, once they reached the land surface, would not be subsequently destroyed or overridden by it.

Summary.—Such are the main phases of water action in connection with a single ice-sheet, on the assumption that the edge of the same did not oscillate backward and forward during the period of its advance or retreat. Were this the complete history of an ice-sheet, the stratified deposits, as they now exist, would be (1) in part extraglacial—those made by waters beyond the extreme advance of the ice; (2) in part supermorainic (supertill)—especially those made by extraglacial waters during the retreat of the ice; and (3) in part submorainic (sub-till)—chiefly those made by extraglacial waters during the advance of the ice, and subsequently buried. The actual relations of the stratified drift to the unstratified are, however, far less simple.

RELATION OF STRATIFIED TO UNSTRATIFIED DRIFT.

Deposits made by extraglacial waters during the advance of the ice, edge not oscillating.—At all stages of the glacial period,

extraglacial streams were depositing gravel, sand, or silt in the valleys through which they flowed. Wherever the ice halted temporarily in its advance, valley trains of greater or less extent may have been developed. All those valley deposits which were made during the first advance of the ice were made on territory which was free from glacial drift. Subsequently the glacier ice overrode them in whole or in part, often burying them beneath its own moraine deposits (till). So too, during the first advance of the ice, the waters which did not concentrate themselves in valleys as they issued from the edge of the ice, made deposits in the form or in the position of overwash plains of gravel, sand, or silt. Well developed overwash plains may have been built up before the ice reached its maximum extension, wherever the ice edge stood for a sufficiently long interval of time in a favorable topographic position. Such overwash plains as were developed during the first advance of the ice, lay upon territory which the ice had never invaded, and constitute, if they still remain, the lowest member of the drift series. Subsequently, in its further advance, the ice overrode these deposits sometimes destroying them and sometimes burying them beneath deposits strictly glacial.

It was not simply by extraglacial streams that stratified drift was deposited during the advance of the ice. The marginal lakes which came into existence during the advance of the ice, and there were many, likewise gave rise to stratified deposits of glacio-lacustrine origin. So far as these were formed upon territory which was free from drift, and subsequently overridden by the ice, they were likely to be buried so far as not destroyed. Deposits formed in the margins of seas at the edge of the ice would be subject to the same changes as those formed in lakes, in so far as they were subsequently overridden by the ice.

Still supposing the edge of the ice not to have oscillated, all the deposits of extraglacial waters made during its first advance, whether of the valley-train, overwash plain, lacustrine or other types, were liable to destruction by the further progress of the ice. So far as they were not destroyed they were liable to bur-

ial beneath unstratified drift deposited by the ice itself. So far as not destroyed, therefore, the exisiting deposits of stratified drift made during the first advance of the ice are likely to occupy the basal position (submorainic) in the drift series, in all the territory subsequently overspread by the ice.

Effect of edge oscillation. — Hitherto the assumptions have been made, for the sake of simplicity, that the advancing edge of the ice forged steadily forward, and that the retreating edge was subject to no temporary advances. It is probable that neither of these assumptions is true. It is believed rather that the advance of the ice was interrupted by many minor oscillations of its edge, both seasonal and periodic, though the sum of the advances was greater than the sum of the retreats during any given epoch, up to the time when the ice reached its greatest extension. When the ice advanced to a certain line, and then receded temporarily, incipient overwash plains, or valley trains, or lacustrine beds, or ill-defined patches of gravel and sand, were doubtless deposited on the territory from which the ice had temporarily receded. The gravel and sand in this case would in general lie, not on a driftless bed, but over deposits made by the ice before its temporary recession. The subsequent advance of the ice would be likely to bury these deposits of stratified drift so far as it did not destroy them. Thus by oscillations of the edge of the ice during the general period of its advance, stratified sand and gravel may have come to be enclosed between beds of till. The extent of the area where this sort of action might take place at any one time would depend upon the amount of oscillation which the ice underwent during its advance. But it may have taken place at many times and places and at many stages in the development of an ice-sheet, so that the interbedding of the two types of drift by this process may have been considerable, in the aggregate, during the advance of the ice.

Deposits made by extraglacial waters during the retreat of the ice. —Stratified deposits made by extraglacial streams during the retreat of the ice of any epoch would remain at the surface

(supermorainic) so far as the ice of that epoch was concerned, except in so far as forward oscillatory movements intervened in the general period of retreat. So far as such movements intervened, their tendency would be to bury or destroy such stratified deposits as were overridden by the temporary advances of the ice, making them intermorainic (inter-till). In a complex body of drift deposited by a single ice-sheet, the edge of which was subject to oscillation, it would not always be possible to tell which beds of intermorainic stratified drift were deposited during the advance of the ice and which during the retreat, though the latter would of course overlie the former.

Deposits made by streams as they issued from the ice. — When streams issued from beneath the ice they often made very considerable deposits at the point of issue (kames, alluvial fans, etc.). In case of simple (without oscillation) advance or retreat of the ice, deposits of this sort made during the maximum extension of the ice and during its retreat would remain undestroyed and unburied so far as ice of that epoch is concerned. Those made by the ice at the time of its maximum extension might rest on a driftless surface or on extraglacial stratified drift deposited in advance of the ice, while those made during its retreat would be likely to lie on till.

The deposits made in this position during the first advance of the ice over any region, were likewise liable to rest on driftless surfaces or on stratified drift deposited in advance of the ice itself. The advance of the ice was likely to destroy them in whole or in part, and bury what escaped destruction. Stratified deposits made at the margin of an advancing ice-sheet the edge of which was not oscillating are therefore likely to occupy a submorainic position, to the limit of ice advance.

In case the edge of the ice oscillated during its advance, the kame deposits made during a recessional phase of an oscillation might rest on the till of the preceding advance phase. Likewise the stratified deposits at the edge of the ice during its retreat, commonly, but not universally, rested on till. Marginal deposits of stratified drift made during a recessional phase

of an oscillating movement during the general retreat, were liable to destruction or burial by the next advance phase. So far as buried, they commonly assumed an inter-till position. Those made during the general recession were of course more liable to escape destruction than those made during the advance.

Deposits made by subglacial streams.—Subglacial streams, as well as extraglacial, made more or less extensive deposits of stratified drift. These were sometimes concentrated along sharply limited channels (eskers), and sometimes more widely spread. They were sometimes made on the rock surface below all drift, but more commonly on unstratified drift (till) which the ice had already deposited. Because of the ever-changing conditions at the bottom of moving ice, it is probable that the ice frequently came to occupy beds which streams had temporarily commanded. Wherever this happened, the stratified deposits were likely to be destroyed in whole or in part, or buried. In the latter case they became intermorainic, if they rested upon till, or submorainic, if on rock. It is believed that very large numbers of beds of stratified drift, of limited extent, became in this way interbedded with till. Subglacial waters which did not organize themselves into regular systems of drainage, must have done a similar work on a smaller scale.

Deposits made beneath the ice during its maximum extension in any epoch, and especially near its edge, stood less chance of being buried by later glacial deposits. Stratified deposits made beneath the ice during its retreat, and especially those made near its edge at any stage, were still less likely to attain an inter-till position.

Deposits made by superglacial and englacial streams.—Theoretically, superglacial streams likewise may have made deposits of stratified drift on the ice or in ice valleys. Practically such deposits were probably not made except near the edge of the ice, for nowhere else was there superglacial drift. Even here they were probably not important. Such accumulations of this sort as were made during the final recession of the ice-sheet were delivered on the land as the ice melted, and should remain

at the surface to the present time, so far as the ice of that epoch was concerned. Such deposits as were made by superglacial streams during the advance of the ice must likewise have been delivered on the land surface, but would have been subsequently destroyed or buried, becoming in the latter case, submorainic. This would be likely to be the fate of all such superglacial gravels as reached the edge of the ice up to the time of its maximum advance.

Streams descending from the surface of the ice into crevasses also must have carried down sand and gravel where such materials existed on the ice. These deposits may have been made on the rock which underlies the drift, or they may have been made on stratified or unstratified drift already deposited. In either case they were liable to be covered by till, thus reaching an inter-till or sub-till position.

Englacial streams probably do little depositing, but it is altogether conceivable that they might accumulate such trivial pockets of sand and gravel as are found not infrequently in the midst of till. The inter-till position would be the result of subsequent burial after the stratified material reached a resting place.

Complexity of relations.— From the foregoing it becomes clear that there are diverse ways by which stratified drift, arising in connection with an ice-sheet, may come to be interbedded with till, when due recognition is made of all the halts and oscillations to which the edge of a continental glacier may have been subject during both its advance and retreat.

It is evident that the stratified drift and the unstratified drift had abundant opportunity to be associated in all relationships and in all degrees of intimacy. It is evident that stratified drift may alternate with unstratified many times in a formation of drift deposited during a single ice epoch. The extent of individual beds of stratified drift, either beneath the till or interbedded with it, may not be great, though their aggregate area and their aggregate volume is very considerable. It is to be borne in mind that the ice, in many places, doubtless destroyed

all the stratified drift deposited in advance on the territory which it occupied later, and that in others it may have left only patches of once extensive sheets. This may help to explain why it so frequently happens that a section of drift at one point shows many layers of stratified drift, while another section close by, of equal depth, and in similar relationships, shows no stratified material whatsoever. It also makes it clear that the interrelations of the two types of drift are, on the whole, less complex than they might have been had all the deposits once made by the ice and its accompanying waters escaped destruction.

After what has been said, it is hardly necessary to add that two beds of till, separated by a bed of stratified drift, do not necessarily represent two distinct glacial epochs.

In any region, which has been affected successively by two or more ice-sheets, the complication of stratified and unstratified drift may be even greater. While the ice of one epoch is likely to destroy in part the deposits of earlier epochs, it is not likely to obliterate them altogether. In some regions, indeed, the full series of one epoch is buried beneath the deposits of a second, as the soil between shows. In addition therefore to the complicated series of stratified and interstratified deposits of a first epoch, the ice of a second developed a full set of its own. A prolonged series of ice epochs might bring about a most complicated set of relations, the complete unraveling of which would be a most arduous task.

In America the exposed portion of the formation made by the ice-sheet which reached the greatest extension — the Kansan[1] — should possess less complex combinations of stratified drift than the drift of the region further north which was affected by two or more ice-sheets. The drift of the region where the Iowan formation is exposed, should present in vertical section, more alternations of stratified and unstratified drift than the Kansan, but less than the drift of the region where the Wisconsin formation occurs, since the drift of this latter region is the product of at least three ice-sheets.

[1] JOURNAL OF GEOLOGY, Vol. III, p. 270; The Great Ice Age, GEIKIE, p. 753 *et seq.*

CLASSIFICATION ON THE BASIS OF POSITION.

In general the conditions and relations which theoretically should prevail are those which are actually found.

On the basis of position stratified drift deposits may be classified as follows:

1. *Extraglacial deposits*, made by the waters of any glacial epoch if they flowed and deposited beyond the farthest limit of the ice.

2. *Supermorainic deposits* made chiefly during the final retreat of the ice from the locality where they occur, but sometimes by extraglacial streams or lakes of a much later time. Locally too, stratified deposits of an early stage of a glacial epoch, lying on till, may have failed to be buried by the subsequent passage of the ice over them, and so remain at the surface. In origin, supermorainic deposits were for the most part extraglacial (including marginal), so far as the ice-sheet calling them into existence was concerned. Less commonly they were subglacial, and failed to be covered, and less commonly still superglacial.

3. *The submorainic* (*basal*) *deposits* were made chiefly by extraglacial waters in advance of the first ice which affected the region where they occur. They were subsequently overridden by the ice and buried by its deposits. Submorainic deposits, however, may have arisen in other ways. Subglacial waters may have made deposits of stratified drift on surfaces which had been covered by ice, but not by till, and such deposits may have been subsequently buried. The retreat of an ice-sheet may have left rock surfaces free from till covering, on which the marginal waters of the ice may have made deposits of stratified drift. These may have been subsequently covered by till during a readvance of the ice in the same epoch or in a succeeding one. Still again, till left by one ice-sheet may have been exposed to erosion to such an extent as to have been completely worn away before the next ice advance, so that stratified deposits connected

with a second or later advance may have been made on a driftless surface, and subsequently buried.

4. *Intermorainic stratified drift* may have originated at the outset in all the ways in which supermorainic drift may originate. It may have become intermorainic by being buried in any one of the various ways in which the stratified drift may become submorainic.

ROLLIN D. SALISBURY.

EDITORIAL.

FROM the preliminary list of papers sent out by the Secretary of the Geological Society of America, it would appear that an unusually interesting meeting may be expected at Washington during the coming holidays. The presidential address by Dr. Le Conte on "The Different Kinds of Earth-Crust Movements and Their Causes" will undoubtedly contain much of interest as the mature result of his long thought on the dynamics of the crust, and this will be expressed in his usual felicitous style.

It is always interesting to note the distribution of the subjects of the papers of so representative a body. Of the forty-two titles announced in the preliminary list, nine may be grouped under the head of areal or local phenomena; nine under the head of physiographic geology, a part of which are discussions of principles and a part of phenomena; eight under glaciology; four under genesis; two under chronology; two under chemical geology; one under palæontology, and one under correlation. This grouping is not, of course, exact, since many of the papers admit of classification under different heads. There is a notable scantiness of papers on petrography, which has usually been so prominent a feature of the Society programme. Doubtless this will be changed in the final list. As a whole, the synopses of the papers indicate matter of more than usual importance, and show a gratifying activity on the part of the members of the Society.

T. C. C.

REVIEWS.

Elements of Geology, a Text-Book for Colleges and for the General Reader. By JOSEPH LE CONTE. Fourth edition, revised and enlarged, with new plates and illustrations. D. Appleton and Company. 1896.

The many excellences of this admirable text-book are too well known and too highly appreciated to need recital in detail. The author has endeavored to select those phases of geology which are most interesting to students and to general readers, and in this he has attained a rare success. In the interest of a clear exposition he has sought to eliminate unnecessary details, and at the same time to set forth the main grounds on which conclusions are drawn. An infallible judgment in so difficult a discrimination is not to be expected. Few who have made the attempt have succeeded better, on the whole, than has Dr. Le Conte. The style of presentation is easy, graceful and lucid. A philosophical tone pervades the book, and the student is never left long without a reminder of the intellectual processes by which conclusions are reached, or, at least, may be reached, for the reasoning, it must be remarked, savors somewhat more of the office than of the field, but the methods of the latter do not lend themselves equally well to easy and brief statement.

Somewhat more than half the book is occupied with dynamical and structural geology, and the rest with historical. The latter could probably be wisely extended at the expense of the former, and some of the dynamical and structural factors could perhaps be treated to advantage in a historical form. For the average student we think the history of the earth and the history of its typical features, treated causally, are more valuable than an analytical exposition of agencies and structures. Geology is essentially a science of the earth as an organism, and the biography of that organism is its most vital aspect as a factor in general education.

The special topics which have received fresh discussion in this revision of the work are earthquakes, the differentiation of rock mag-

mas, the Cambrian, the structure and affinities of trilobites, of Mesozoic reptiles, and of Mesozoic and Tertiary mammals, and the causes of glacial and other geological climates. Earthquakes are treated in a relatively elaborate way, which is perhaps warranted by the popular interest they awaken. They are, however, given more space than rivers, which have incomparably greater geological and educational importance. It would, we believe, have been better to bring the treatment of rivers and of topographic evolution well up to date even at the expense of a reduction of the space previously given to earthquakes, and to other less universal phenomena. The brief statement of magmatic differentiation, the greater emphasis placed on the Cambrian, and the later results of research on the trilobites, reptiles and mammals are all welcome additions. Much less, we fear, can be said in commendation of the discussion of glacial phenomena. The opening statement (p. 568) relative to the great oscillations of the earth's crust, and especially the unqualified assertion that "the glacial epoch is characterized by an *upward* movement of the crust in high-latitude regions, until the continents in those regions stood 1000 to 3000 feet above their present height," appears to the reviewer to need revision; at least, the student and the general reader should be informed that this once current doctrine has been cast aside by many of the most experienced glacialists on both sides of the Atlantic. That there was a very notable elevation in the *Pliocene* period is not doubted, indeed, among its strongest proofs are the very phenomena appealed to in proof of elevation in the glacial period. Unless the modern science of geomorphy goes for naught, the elevation that produced the fjords and the ragged borders of the northern coasts took place very much anterior to the glacial period. Concurrent with this evidence there has been gathered within the last few years a great mass of data which indicates that during much of the glacial period only a moderate — indeed, in part, a rather low — altitude prevailed. A conservative author may well be pardoned for not accepting these new doctrines, but scarcely for leaving students in total ignorance of them. A specific error of much significance is the statement, following Hilgard, that the Lafayette sands and gravels contain northern bowlders, and their consequent reference to the glacial period. Crystalline pebbles, presumably of glacial origin, occur in the sands and gravels of the Natchez formation, which bears some resemblance to the Lafayette, because largely derived from it, and hence has

been confounded with it. The Natchez formation, however, lies unconformably on the Lafayette, as the writer has demonstrated. The contact shows that the Lafayette had acquired its peculiar ferrugination and partial induration and had been deeply eroded, before the Natchez formation was deposited. The latter holds pebbles of the brick-red, semi-indurated sand of the former in its unconformable layers at the contact. The Lafayette sands and gravels are wholly removed from genetic connection with the glacial series, and the inferences from their "torrential" character should be entirely dismissed. The extraordinary fact about the lower Mississippi valley is the *scantiness* of glacio fluvial deposits of a coarse nature.

The term Champlain is not unlike charity in its mantling function, and the pall of the latter is usually much needed in reviewing anything that goes under the caption of the former. Strictly applied to the marine deposits of the Champlain valley and their chronological equivalents, it serves a useful purpose, but when it is made to cover not only these, but the deposits of several different stages of the glacial epoch, its utility is of the inverted order. There is some slight mitigation of these "inherited blunders," to use the expressive phrase of Goode, in the work in hand, but only slight. The Champlain epoch is made to include the low altitude deposits without regard to how they may be sandwiched among the glacial stages. The result of this high-altitude, low-altitude mode of classification is a serious misconception of the real nature of the history of the glacial period.

The weakest points in the book are found in the treatment of the two ends of the geological column, the pre-Cambrian, which is very scantily treated, and the post-Pliocene which largely neglects the investigations of the last decade.

In the discussion of the antiquity of man in America, the doubtful nature of the evidences associated with the auriferous gravels of California are judiciously stated, but the more distant eastern relics are treated with less reserve. The Babbitt find at Little Falls, Minn., is cited as a "good example" of these, and perhaps it is a good example, as the canons of good science were quite ignored in giving it to the public, and the reference of the relics to the same age as the deposition of the beds in the superficial portion and in the talus of which they are found involves a palpable absurdity, as explicitly shown by Holmes. It would seem that students should be taught frankly that the evidence of Quaternary man in America is sharply challenged,

and that, until the trashy portion of the evidence is purged away and solid data are produced, no conclusions can safely be drawn.

These specific criticisms, which have required some little fullness of statement, give disproportion to this review, and it needs correction by a reaffirmation of the very high excellence of the work as a whole. T. C. CHAMBERLIN.

The Oldest Fossiliferous Beds of the Amazon Region. By FRIEDERICH KATZER, chief of the geological section of the Pará Museum. Boletim do Museu Paraense, Vol. I, No. 4, pp. 436–438. Pará, Brazil, 1896.

It has already been satisfactorily shown that of the Palæozoic series we have in the Amazon valley rocks of Silurian, Devonian, and Carboniferous ages. Whether there is any Cambrian and Permian remains to be determined. The beds below the known Palæozoic rocks are gneisses, crystalline-schists, etc., referred to the Archæan. It is not impossible that some of the quartzites and mica-schists are Cambrian and Lower Silurian.

Upper Silurian beds have been recognized in the Amazon region thus far only at one place, mainly on the Rio Trombetas at Viramundo Falls, where fossils have been found.

In 1895, however, Dr. João Coelho made on the Rio Maecuru a rich collection which has been presented to the Pará Museum. After a careful examination of these rocks, graptolites have been found in them, thus proving the existence of Upper Silurian rocks in the Maecuru valley. This is the first discovery of these fossils in Brazil.

It is worthy of mention, also, that these graptolites were found in beds composed principally of siliceous spicules of sponges. These spicules are visible to the naked eye, but they are better seen with a lens magnifying ten to twenty diameters, or in thin microscopic sections. These sponge remains are the first of the kind found either in the Amazon region or in the Palæozoic beds of Brazil.

The author has recently presented a memoir on the geology of the Amazon, and especially on the Archæan rocks, to the Academy of Bohemia, based on his studies of a series of specimens from the zone north of Alemquer, and of another set brought by Dr. Goeldi from his scientific expedition to Guiana in 1895. In an early number of this Boletim he will give a résumé of that paper.

One of the chapters of the paper is on the Devonian rocks. From the Devonian beds on the Rio Maecuro Dr. João Coelho brought a large number of fossils, which show the existence of beds literally full of mollusks, principally brachiopods, proving the existence of members of the Devonian series more recent than has been supposed to exist there.

The study of these materials shows the necessity of a study of the stratigraphy of the Amazon region in order to fix the position of these fossiliferous beds and to settle finally the geologic structure of this part of South America. It will be the first important task of the geological section of the Pará Museum to give a correct synopsis of these structural features. J. C. BRANNER.

The Formation of the Quaternary Deposits of Missouri. By JAMES E. TODD. Reports of the Missouri Geological Survey, Vol. X. State Printer, Jefferson City, 1896.

This excellent report describes in detail the glacial drift which covers the northern portion of Missouri, treating of it analytically in its various phases, including the forest beds and old soils that are embraced within the drift. This is followed by a description of the loess and its associated deposits; of the terraces and ancient channels, and of the alluvial deposits of the existing streams. Following this exposition of the observed facts, the leading problems that arise from them are taken up and considered in succession. Under this head is discussed the former existence of a barrier between the Missouri and Gasconade rivers, which the author regards as an important factor in explaining the phenomena above that point. The origin of the loess is considered and the conclusion reached that it had a fluvio-lacustrine origin. In considering the erosion of the Missouri River, it is concluded that it had unusual facilities for rapid excavation of its channel. A postglacial deformation of the Pleistocene plain is advocated. The method of deposition of the drift is discussed and some modifications of the simple glacial hypothesis suggested. The recent classification of the drift sheets is adopted. The report is closed by a brief, clear sketch of the sequence of events. The discussion is careful and judicial in tone. The report is well illustrated with photographic views and profiles and the necessary maps. T. C. C.

Der Eläolithsyenit der Serra de Monchique, seine Gang- und Contactgesteine. By K. v. KRAATZ-KOSCHLAN and V. HACKMAN. Tschermak's Mineralogische und Petrographische Mittheilungen, Vol. XVI, pp. 197–307, Pls. IV and V. 1896.

The rock making up the mass of the Serra de Monchique in the southern part of Portugal, first described as "granite" by Bonnet in 1850, was later recognized as a new type by Blum in 1861, and by him given the name *foyäite*, from the dominant peak of the range. It is today known as the foyäite type of the elæolite syenites. The present paper, while largely taken up by detailed petrographic descriptions, is professedly a study of the geological relations of the various rocks.

The elæolite syenite *massif* is roughly elliptical in area, with its longer axis, 15.5 kilometers, extending nearly east and west. Its breadth is about 5.5 kilometers. It consists essentially of two main mountain ridges, separated by the northeast and southwest valley in which the village of Monchique lies. The more easterly of these two ridges takes its name of the Picota from its dominant peak (774 meters), while Mount Foia (902 meters) lends its name to the western ridge. The whole elliptical area is enclosed by the shales and sandstones of the Culm, and the intrusion probably took place within Carboniferous time.

A zone of contact metamorphism was traced around a large portion of the area, and is assumed to completely surround it. Near the contact the normal syenite becomes finer grained, and is either a mica-foyäite, in which the non-micaceous dark minerals have almost disappeared, or has the usual ægirine-augite replaced by ægirine. These changes are accompanied by the addition of låvenite, spinel, and tourmaline. The surrounding metamorphosed sediments consist of altered quartzose *grauwacke*, black *hornfels*, and *knotenthonschiefer*. A cordierite-mica-hornfels which occurs as an inclusion in the elæolite syenite is regarded as an altered diabase. So-called "diabase hornfels" occurs in two places in the metamorphic girdle and is assigned a similar origin. The width of the contact zone varies from a few meters to over a hundred meters, but is in general not so wide as would have been expected in the case of an intrusive granite mass of equal size. It is considered that the alteration was conditioned by the temperature of the eruptive mass and not, to any great extent, to pneumatolytic processes.

Numerous dikes cut the syenite massif but have not been traced

into the surrounding sedimentary rocks. Their strike is generally north and south, northeast and southwest, and northwest and southeast. Only one was noticed with an east and west strike, and their course is accordingly frequently nearly at right angles to the trend of the mountains. They are most commonly from one-half to one meter in width, the monchiquites being particularly variable. As a whole they form a series of differentiated rocks genetically related to the main elæolite syenite. The observed types are: bostonite-porphyry, tinguaite, nepheline-syenite-porphyry, camptonitic tinguaite, and camptonitic and monchiquitic rocks.

The petrography of all the rocks mentioned has been worked out with considerable detail, and is accompanied by several chemical analyses, forming a valuable contribution to the literature of these interesting types. It is shown that the nepheline-syenite of the Foia is poorer in the nepheline than the rock of the Picota, and closely resembles the pulaskite of Arkansas. It presents many features which point to a quicker solidification at less depth than is indicated in the case of the Picota facies. The study of the dike rocks brings out many interesting and suggestive points which can only be referred to in a brief review. With the suggestions embodied in Pirsson's recent paper[1] on the analcite series of rocks in mind, the rôle played by that mineral in these Portuguese rocks, and the description of a so-called "leucite-tinguaite-vitrophyre" with its high alkali contents and devitrified glassy base, become doubly interesting.

The microscopic petrography of the altered sediments is minutely described, and the paper ends with an excellent summary, in which the general sequence of the intrusive activities is presented. The plutonic mass of the Picota, slowly cooled at great depth, is the oldest portion of the *massif*, and probably also underlies the rock of the Foia, which is regarded as an already somewhat differentiated, more acid, upper portion, which solidified nearer the original periphery of the mass. Certain *schliere* in the Picota area are similar to the rock of the Foia. Corresponding to these more acid differentiation products, are the tinguaite dikes, as later intrusions or *Nachschübe*. Basic differentiation products are represented by slowly cooled theralitic rocks (essexite and teschenite), and their corresponding dikes of the camptonite-monchiquite series. These rocks are thought to be younger than the tinguaites, but no satisfactory evidence was obtained

[1] This JOURNAL, Vol. IV, p. 679.

on this point. The youngest intrusion of all is represented by the leucite-tinguaite-vitrophyre.

It is to be noted that the process of differentiation here described, inasmuch as the more acid facies of the elæolite syenite occur on the periphery of the mass, differs from those described by Brögger, in which the more basic constituents have tended to migrate toward the cooling surface. This difference, coupled with the fact that the authors refer only once, very casually, to the whole intruded *massif* as a laccolite, gives cause for regret that they were not able to devote more time to the study of field relationships than was actually at their disposal.

F. L. RANSOME.

Geological Survey of Canada. G. M. DAWSON, Director. *Ann. Rept. U. S.*, Vol. VII, 1894. Ottawa, 1896.

The summary report of operations is followed by a report on the area of the Kamloops map-sheet by Dr. G. M. Dawson, a report of an exploration of the Finlay and Oomenica rivers by R. G. McConnell, a report upon the country in the vicinity of Red Lake and part of Berens River, Keewatin, by D. B. Dowling, a report upon a portion of the eastern part of Quebec, by R. W. Ells, with a chapter upon the Laurentian north of the St. Lawrence, by F. D. Adams, a report upon the surface geology of portions of New Brunswick, Nova Scotia, and Prince Edward Island, by R. Chalmers, and the usual statistical tables and notes on the analyses and collections made.

Within the year an important change in the management of the survey occurred, Dr. A. R. C. Selwyn, who had served as director since the retirement of Sir W. E. Logan in 1869, being granted leave of absence and the following January receiving superannuation. Dr. G. M. Dawson, his successor, was recalled from the field early in October and has since been in charge of the work. Twelve parties were in the field. Dr. Dawson himself spent some time in the Kamloops and adjoining regions investigating recent mining developments. In the Cariboo mining districts the study of the changes in drainage consequent upon glacial conditions was undertaken as likely to yield important results as to the distribution of the auriferous river gravels. The history of these gravels and their association with the glacial beds is traced in detail in the Kamloops report. Mr. R. G. McConnell spent the season in the foot-hills of western Alberta and in the south-

ern part of the west Kootanie district. Mr. J. B. Tyrrell conducted an expedition through the "Barren Grounds," but owing to the short time which elapsed between his return and the publication of the report, only brief notes on the trip are given. A somewhat fuller account of the expedition of 1893 is, however, inserted. Dr. R. Bell and Mr. W. McInnes spent the season in Ontario on work previously begun. Among other points, Dr. Bell determined that the gneissic area between St. Mary's River and Gonlis Bay is not connected with the granitic tract lying to the northeast, but forms an isolated mass. Dr. R. W. Ells was engaged upon work along the Upper Ottawa and adjacent regions. Some interesting points of structure were observed at various places. While it is very evident that the syenites or granites, as a whole, in this section are intrusive in the crystalline limestone, some portions of them are of comparatively recent date. At one point they have disturbed horizontal beds of Calciferous and Chazy, and at another have penetrated and altered the Potsdam. Mr. A. P. Low spent the seasons of 1893–4 in exploring the interior of Labrador and his report, when it shall be completed, promises to correct the popular notion that Labrador Peninsula is a waste, barren region totally unfit for habitation. One of the important results of the exploration is the discovery of a great tract of Cambrian rocks carrying rich beds of iron ore. The striæ of the region show that the ice of the glacial period flowed off in all directions from the central area. Mr. R. Chalmers concludes as a result of the season's work that the facts altogether demonstrate that Nova Scotia has been glaciated entirely by ice which gathered upon its own surface, and afford no evidence of a great ice-sheet crossing the Bay of Fundy and overriding that peninsula. Mr. Whiteaves reports that the second part of the third volume of *Palæozoic Fossils*, consisting of a monograph upon the fossils of the Guelph formation of Ontario, is completed and ready for publication.

The volume as a whole is well printed and well illustrated and forms a most valuable addition to the literature of the region. The area in which the Canadian Survey works is not only one of great extent, but also of great complexity. It is furthermore to a considerable extent unsettled and unexplored. As a result, the cost of geological investigation is relatively high. In view of these facts, and the known wealth in mineral resources of much of the partially explored country, it would seem that the director's plea for larger appropriations is well founded. It is to be hoped that the government

will find itself able to rapidly expand the work and give the new director adequate means for the remarkable opportunities for investigation which the region affords. H. F. BAIN.

Proceedings of the Indiana Academy of Science, 1895; Geological Subjects.

Six papers on purely geological topics were read before the Indiana Academy during the year, besides a number of others of more or less interest and value to geologists. The most important geological paper of which an abstract is published is that by A. H. Purdue upon the Charleston, Missouri, earthquake of October 13, 1895. The shock or shocks of that earthquake were of sufficient force to break plate glass windows, crack brick walls, and to throw down brick chimneys at several places, and it seems to have been felt over an area of more than 400,000 square miles. The author might have called attention to the fact that within the area affected there are a score or more of colleges and universities at which geology is taught, but that not one of these institutions had a seismograph or seismoscope in working order, and that there were therefore no accurate observations made upon the time or nature of the shocks.

In "Some Minor Eroding Agencies," by J. T. Scovell, attention is directed especially to the work of burrowing animals: ground hogs, gophers, badgers, prairie dogs, cray fishes, and burrowing insects of various kinds. When Mr. Darwin mentioned the geologic importance of earthworms it was generally thought that he was making the most of a very small affair, but when his data were completed every one was amazed to find the results so important. Mr. Scovell's points are doubtless well taken, but if he will make and record his observations in such a manner as to give them a *quantitative* value, he will do the science of geology an excellent service. In some instances this is impossible, but in others it is not.

It is cause for congratulation that the legislature of the state of Indiana recognizes the importance of coöperating with the State Academy of Science. Show us a state in which the legislature and the people demand of the scientific men scientific results, regardless of whether they have immediate "practical" value and we will show you a state that contributes its full share to the advancement of science and of civilization. J. C. B.

Areal Geology of Missouri (Mo. Geol. Surv., Vol. IX, sheets 1–4, 412 pp., 4 folio topographic and geologic maps, 24 plates, 53 figures. Jefferson City, 1896.)

The volume includes four sheet reports: (1) Higginsville, 1892; (2) Brevier, 1894; (3) Iron Mountain, 1894; (4) Mine La Motte, 1896. These reports were issued as independent reports for separate distribution, but for library uses are bound together in a single volume uniform in style and size with the remaining volumes issued by the present survey. H. F. B.

Om kvartära nivåförändringar vid Finska viken (On Quaternary Changes of Level near the Bay of Finland). By GERARD DE GEER. Sveriges geologiska undersökning Afhandlingar och uppsatser; No. 141, pp. 17. Stockholm, 1894.

The author gives an account of some observations in 1893 on the east coast of the Baltic. By studies in the field and by an examination of the topographic charts made by the Russian government three ancient shore lines were traced, extending around the east end of the Bay of Finland and southward close to the German boundary. The highest of these are referred to the "*late-glacial*" age, the time of recession of the Baltic ice. Northeast from Helsingfors it reaches an elevation of 152 meters above the present level of the bay, but toward the east and south it falls a little below thirty and twenty meters above this level. There are indications that the province of Curland and even Northern Germany were affected by the tilting which deformed this beach. Its position is such that the lakes Peipus, Ladoga, and Onega must have been arms of the Baltic at the time it was made. Another series of terraces marks the Ancylus stage of the Baltic. This maintains an altitude of from 45 per cent. to 50 per cent. of that of the late-glacial beach. A third well-marked beach line is referred to postglacial times. This is the lowest of the three, having an elevation of only four meters above the present level of the bay of St. Petersburg. To the west and north it rises to several times this height. The occurrence of oak and the peccary in deposits inside of this beach is referred to as evidence of a milder climate in an earlier postglacial time. J. A. UDDEN.